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THE MODERN SPECTROSCOPE. XII.

THE TULSE HILL ULTRA-VIOLET SPECTROSCOPE.

By WILLIAM HUGGINS.

THE spectroscope which I designed and had constructed during the seventies for my original work on photographing the spectra of the stars,[1] was arranged to include the whole of the ultra-violet region of the light from the heavenly bodies which reaches the Earth.

I had at my command a refractor of fifteen inches aperture, and a Cassegrain telescope of eighteen inches aperture, both belonging to the Royal Society. I chose the latter instrument for my work, notwithstanding the drawback of some want of permanency of the collimation of the mirrors, on account of the freedom of a reflector from the outstanding chromatic aberrations of a refractor, and also because by the employment of Iceland spar for the prism and quartz for the lenses, the whole of the more refrangible part of the spectrum could be photographed, at least as far as the absorption of our atmosphere allows rays of small wave-length to pass.

[1] "On the Photographic Spectra of the Stars." *Phil. Trans.* 1880, Part ii, p. 669.

The Cassegrain telescope, which has mirrors of speculum metal of very fine defining power, was made by Sir H. Grubb. In 1882 it was mounted, by the novel device of a double declination axis, one axis moving within the other, as a twin telescope, together with the fifteen-inch refractor, upon the same equatorial stand. This instrument has been used chiefly for spectroscopic work, but last year advantage was taken of the fine definition of the specula to make some crucial observations of the character of the image of Nova Aurigæ.[1]

The early arrangement employed in 1876–1879 consisted essentially of a small spectroscope containing a single prism of Iceland spar, and lenses of quartz, the slit of which was placed in the principal focus of the great speculum, eighteen inches in diameter, of the Cassegrain telescope, the small convex speculum having been removed.

In this instrument the plan was adopted for the first time of turning the jaw plates of the slit into mirrors, in which the objects to which the instrument was directed could be seen by reflection at the same time as the slit itself. In the first instance polished silver was used for the reflecting substance; afterwards very thin plates of quartz, silvered at the back, the edges of which formed the slit; and finally in the new spectroscope attached to the refractor,[2] speculum metal was found to fulfil very satisfactorily the necessary conditions of giving a permanently reflecting surface, and furnishing true edges for the slit. In this early instrument the images of celestial objects reflected from the mirror-jaw plates were observed through the hole in the great speculum by means of a small telescope fixed in the place of the eyepiece.

The advantage which this form of spectroscopic arrangement possessed of reducing the loss of light by reflection to that at the surface of one speculum only, was accompanied by some draw-

[1] In this instrument, which is of course free from chromatic aberration, the images of Nova Aurigæ and of the star near it were indistinguishable in character under a magnifying power of 700 diameters. Both appeared equally stellar. *A. N.* 3211. *A. and A.* April, 1894, p. 314.

[2] For photograph and description see *Astronomy and Astro-Physics.*

backs. The spectroscope, though made as small as possible, was larger than the four-inch hole in the speculum, and blocked out some light. The adjustments of the spectroscope itself, and also of its relation to the speculum, could only be made with some inconvenience at the top of the tube. For the same reason, unless the telescope was directed to an object very low down, it was necessary, at some loss of time, to unclamp it in declination and bring the spectroscope-end within reach in order to insert or to change the photographic plate.

There was the further disadvantage that in consequence of the large ratio of aperture to focal length of the great speculum, namely, $\frac{f}{7\frac{1}{2}}$, the collimator had to be made very short. Consequently with one prism, to which the spectroscope was necessarily restricted on account of size, either light or the necessary purity of the spectrum had to be sacrificed. If the slit were opened wide enough to just include, or even nearly so, the image of a star, its angular magnitude relatively to the dispersion was too great for the needful resolution of lines, and therefore, as a matter of fact, the slit was always used too narrow to receive more than a part of the light of a star, with the great disadvantage of long exposures.

The new instrument is free from these disadvantages, though in one respect it comes short of the earlier arrangement, since there is additional loss of light from reflection at the second speculum. The Cassegrain telescope is restored to its original form, and the collimator of the new spectroscope passing up through the hole in the large speculum, the slit is placed within the telescope tube at the focal plane after reflection from the small convex speculum.

In Fig. 1, Plate XVI, the collimator is seen within the telescope tube; in Fig. 2, Plate XVII, the remaining part of the spectroscope, outside and below the telescope tube, is shown.

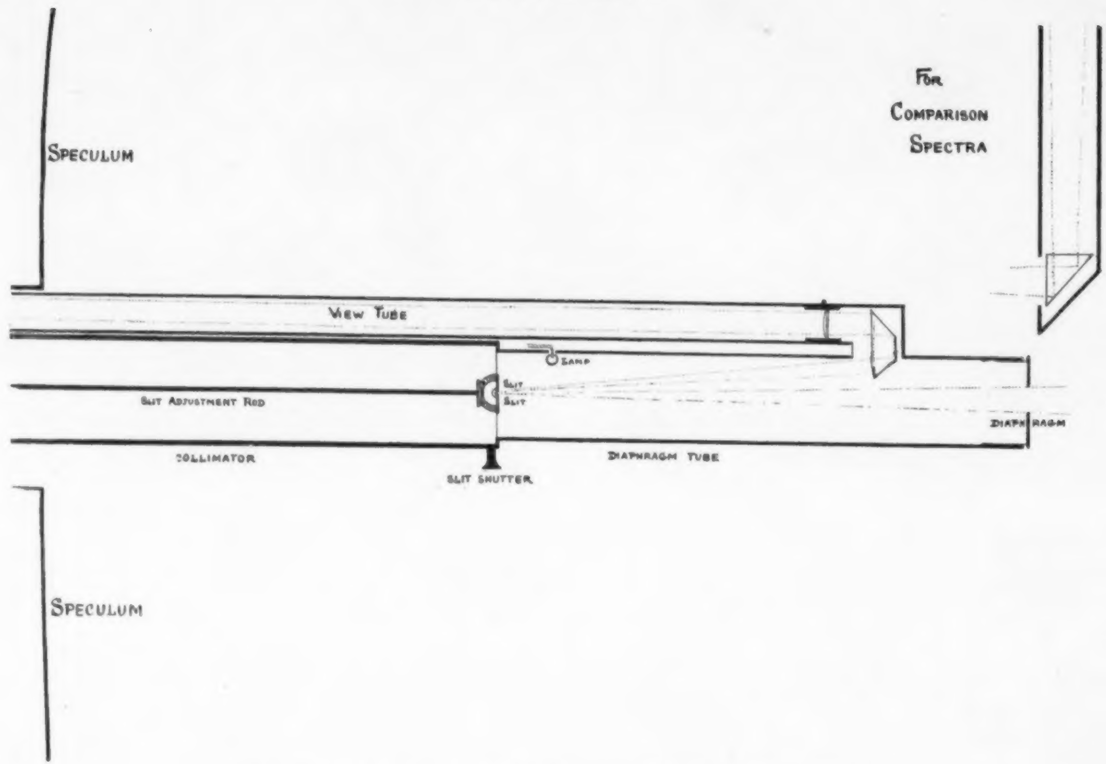
Returning to Fig. 1, the diagram explains itself. The slit is adjusted by means of a rod, which in Fig. 2 is seen to pass below the spectroscope and to terminate in a graduated head.

Behind the slit slides a small shutter which closes the central half of the slit, to protect the part of the plate on which the star's spectrum falls, when, either before or after exposure, narrow comparison spectra are photographed through the outer parts of the slit, above and below the star's spectrum.

In front of the slit extends a tube twelve inches long, furnished at the end with a sliding diaphragm having an opening of such a size as to exclude all light except that reflected from the small convex mirror.

A very successful arrangement of the slit-mirror method has been adopted by which the slit, together with a small field of stars, can be conveniently seen by an observer looking into the diagonal eyepiece, shown in Fig. 2. This eyepiece, by means of the clamp, can be brought into and then fixed in the position which is most convenient for observation. The polished slit-plates of speculum metal are slightly inclined so that the light which does not pass on through the slit is reflected, as shown in Fig. 1, to one side of the diaphragm-tube. There it falls upon the first face of a prism of such a form that after two internal reflections it returns along the small view-tube placed by the side of the collimator. A few inches below the second surface of the prism is placed a small achromatic lens having a focal length equal to its distance from the slit. The rays after passing through it are rendered parallel, and then pass on without loss, until at a little distance from the eyepiece, Fig. 2, they encounter a second achromatic lens. This has a focal length of about six inches, and with a suitable eyepiece gives a well-defined and bright view of the small field of stars upon the slit-plates. On a dark night, or when an object of finite magnitude, as a planet or a nebula, is not upon the slit, the opening of the slit becomes lost to view. For the purpose, under these circumstances, of illuminating the slit artificially, a very small incandescent lamp made of ruby glass is inserted through the side of the diaphragm-tube a little way from the slit, Fig. 1. It is enclosed so that light passes only upon the slit-jaws. From the position of the lamp it will be seen that its light is not reflected back from the slit in the

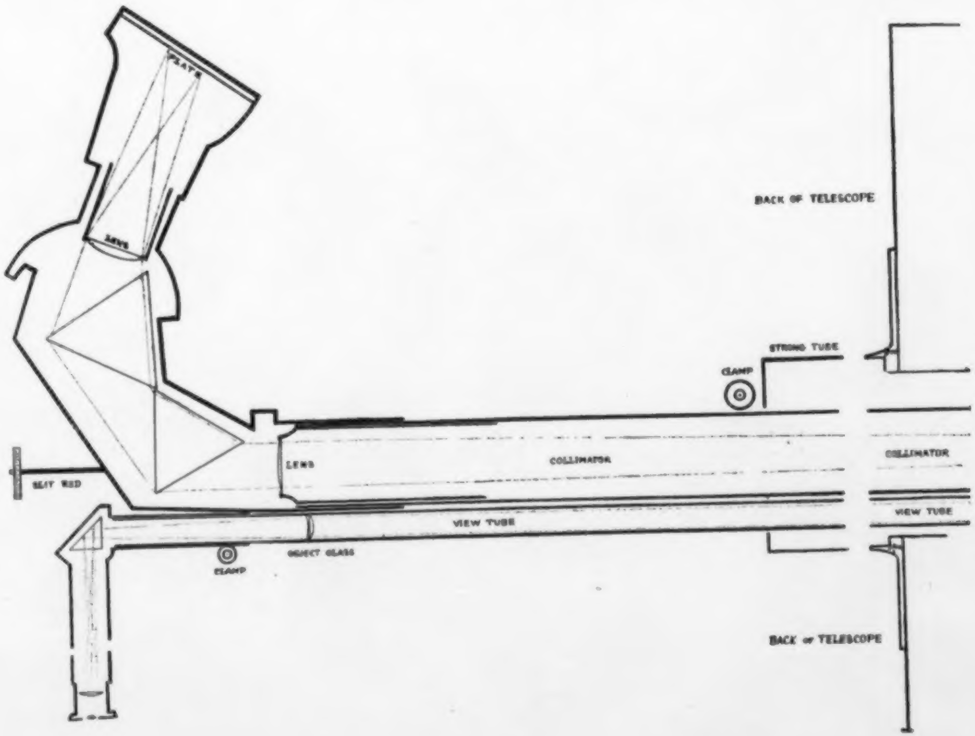
PLATE XVI



THE TULSE HILL ULTRA-VIOLET SPECTROSCOPE

FIGURE 1

PLATE XVII



THE TULSE HILL ULTRA-VIOLET SPECTROSCOPE

FIGURE 2

direction to pass to the observer's eye. The slit-jaws are illuminated by that small part only of the red light of the lamp which is scattered from the mirrors in consequence of imperfect polish. This feeble illumination is found in practice to be just what is needed to show the slit distinctly, without overpowering faint objects. A variable resistance is placed within reach, so as to make it easy to obtain with exactness the precise degree of illumination which is most suitable to each object. From the position of the lamp any light which passes through the slit does not pass on to the collimator-lens, but is absorbed by the blackened inner surface of the tube. The ease with which the slit can, by this arrangement, be placed with precision upon a star, or upon a small part of a planet or of a nebula, is all that can be desired.

In Fig. 1 the detached tube terminated by a right-angled reflecting prism forms part of the arrangement for throwing into the slit the light from sparks or flames for comparison. When in use this tube, which slides through an outer tube furnished with the necessary adjusting screws fixed upon the outside of the telescope-tube, is pushed in until the reflecting prism comes in front of the opening at the end of the diaphragm-tube before the slit. The light from the spark, vacuum tube, or flame outside the great telescope passes through a double quartz-combination fixed in the tube near the outer end, by which it is made to converge to a focus upon the slit, and then to diverge at a little greater angle than is necessary to completely fill the collimator-lens.

When not in use, this tube can be wholly withdrawn outside the telescope-tube, so as not to intercept any light from the great mirror.

Fig. 2 shows the prism-box, which contains two prisms of Iceland spar, each with a refracting angle of 60°. These were made for me by Mr. Hilger and have been cut very successfully. The smaller prism, which limits the beam that can pass through them, has a length of 2½ inches with a height of 1½ inches.

It was decided to work with the prisms in a fixed position,

though this position can be varied from time to time for different parts of the spectrum. The prisms and camera are therefore provided with clamps, by which, when all the necessary adjustments of the prism, of the camera-lens and of the plate-holder have been made, the whole apparatus can be secured rigidly in position. All the different adjustments are provided with divided scales, so that if it were necessary for any reason to dismount any part of it, the instrument could be put back again into its former position with great exactness.

The instrument is provided with two camera-lenses, one of about 5¾ inches, which is now in use for nebulæ, and a lens of 9 inches for stellar spectra, the larger scale of the spectrum making it more independent of the granulation of the gelatine film.

A range of spectrum from F to a little beyond S, which with the shorter camera-lens measures about ⅞ inch in the plate, can be obtained with good definition throughout, and also quite free from any duplication due to the double refraction of the spar. The spectrum indeed extends some distance beyond S, but after this point there is a little falling off in definition. The diameter of the collimator lens is 1⅜ inches, that of the camera lens being slightly greater.

For greater lightness the camera-box is made of aluminium, and as the slit is placed in the direction of the star's motion, this box stands up in a nearly vertical position when the telescope is in the meridian, which is a very favorable one for freedom from flexure.

The spectroscope, as a whole, is secured by means of strong clamps within the large tube which screws on to a plate fixed on the base of the telescope-tube behind the great speculum. It can therefore be attached and removed from the telescope without any derangement of its internal adjustments.

Through the strong supporting tube the spectroscope, as a whole, can slide a few inches for the purpose of a first rough adjustment of the slit to the focal plane; the final adjustment is then made by a fine screw which gives a slow motion to the small convex speculum.

The necessary breadth can be given to the spectra of stars in two ways, either by allowing the star's image to trail in the slit, or by means of a concavo-cylindrical lens of quartz which is mounted in a short tube, which can take the place of the sliding diaphragm-tube at the end of the tube before the slit.

The long equivalent focal length of the Cassegrain form of telescope is of advantage in many cases of modern astronomical spectroscopy, where it is desirable to have images of considerable dimensions upon the slit-mirrors. It will become, doubtless, of increasing importance to be able to photograph separately the spectra of adjacent parts of the surfaces of nebulæ, and of the planets, and to obtain, without enlargement, sufficient breadth of spectrum in the case of very small nebulæ. Further it will be desirable to bring separately upon the slit, and to maintain there, the components of binary and multiple stars, and also the stars involved in nebulæ. The Cassegrain form furnishes the means of conveniently obtaining a long equivalent focal length, while the instrument itself, and the building covering it, remain of moderate dimensions.

ON THE SPECTROGRAPHIC PERFORMANCE OF THE THIRTY-INCH PULKOWA REFRACTOR.

By A. BÉLOPOLSKY.

WHEN a spectrograph similar to that of the Potsdam Observatory was ordered for this observatory, in 1890–91, it was decided to attach it to the fifteen-inch refractor for the purpose of undertaking, as time permitted, preliminary researches in the domain of celestial spectroscopy. After the spectrograph had arrived here I suddenly received (November 9 / 21, 1891) an order from the Director "to employ all means, without sparing money or time, to adapt the spectrograph as quickly as possible to the great thirty-inch refractor."

This by no means easy task could of course be only partially carried out at the time, but it was nevertheless interesting to make a test of the instrument, although careful reflection would lead *a priori* to the conclusion that no particularly fruitful results could be obtained, for various reasons, among which are these:—the objective is corrected only for the visual rays, the dimensions of the spectrograph were not designed for the large refractor, handles for the slow-motions as well as an adapter were lacking, provision was not made for observing steps, and, finally, the dome was too small in many positions of the instrument when the spectrograph was attached.

After the most indispensable, but still inadequate, accessories were ready, toward the middle of the summer of 1892, my observations were begun and have been continued in the summer months of 1893 and 1894.

I wish now to communicate some of the experiences I have thus far had with the instrument, especially since I had an opportunity last winter to attach the spectrograph to our new photographic telescope also, and thus secure a series of spectrograms which permitted a comparison of the results obtained with the two refractors.

One of the most important investigations for the objective is the determination of its color curve. This had already been done by H. Struve, according to Vogel's method, but his observations related to only four points in the visual portion of the spectrum, and they are also affected by the imperfect achromatism of the eye. It was therefore quite interesting to secure a series of spectrograms in order to obtain a more complete idea of the achromatism of the objective. Accordingly spectrograms were made on isochromatic and on ordinary plates; for the former the slit was placed in the visual focus of the objective, for the latter in the focal planes for $H\gamma$ and $\lambda 4410$. The measurements were made with the Töpfer microscope, the spectrogram being placed at right angles to the screw, and covered with a solar spectrum plate for the purpose of orientation.

The diameters of the circles of chromatic aberration in the visual portion of the spectrum are reduced to the focal plane of the rays $\lambda 6000 - 5000$. The following table was obtained by platting upon millimeter paper sixteen measured diameters on each of the three spectrograms of stars of Classes I and II, and then drawing the curve, the hundredth of a millimeter being certain:

λ	Diameter	λ	Diameter	λ	Diameter
	mm		mm		mm
6000	0.00	5400	0.15	4800	0.17
5900	0.08	5300	0.10	4700	0.37
5800	0.15	5200	0.05	4600	0.61
5700	0.22	5100	0.02	4500	0.88
5600	0.23	5000	0.01	4400	1.18
5500	0.19	4900	0.05	4300	1.49

H. Struve gives the diameters in the planes D–C as follows:

λ	Diameter
	mm
6560	0.16
4860	0.35
4340	1.77

It will be seen that these values are greater than those given by the spectrograms, but the difference is explained by the fact that

Struve's measurements are affected by the chromatic aberration of the eye.

The spectrogram on orthochromatic plates (erythrosin) commences near D, reaches a maximum of intensity at λ 5500, decreases to λ 5000, and then becomes more intense up to F; then it diminishes as the width increases to $H\gamma$, where the spectrum ceases to be measurable.

The measurement of the diameters on ordinary plates gave the following results for the focal plane of λ 4400:

λ	Diameter	λ	Diameter	λ	Diameter
	mm		mm		mm
4270	0.33	4380	0.04	4443	0.09
4310	0.20	4400	0.00	4453	0.25
4340	0.08	4415	0.03	4668	0.56

The intensity of the spectrum is so slight at λ 4270 and λ 4670 that no lines are visible at those points, and the measurable part of the spectrum under ordinary circumstances lies between λ 4300 and λ 4440.

If the slit is adjusted to the focal plane of λ 4341, and the spectrum of a star of Class I is photographed, the following diameters are obtained:

λ	Diameter	λ	Diameter	λ	Diameter
	mm		mm		mm
4655	0.94	4352	0.12	4308	0.16
4550	0.73	4341	0.00	4272	0.26
448	0.42	4335	0.05	4227	0.40
4383	0.22	4326	0.09	4217	0.48

It therefore appears that the diameter increases very rapidly on each side of $H\gamma$ in both of these cases, and hence, as well as for other reasons to which we shall refer again, the intensity decreases rapidly, so that here also the measurable portion of the spectrum lies between λ 4300 and λ 4450.

Let us now compare these results with those obtained from measurements on spectrograms secured with the photographic telescope. On account of the given focal length of the collima-

tor, only 250^{mm} instead of the whole 330^{mm} of aperture of the objective could be utilized.

Collimator Setting = 47		Collimator Setting = 45	
λ	Diameter	λ	Diameter
	mm		mm
4800	0.06	4800	0.03
4450	0.01	4410	0.07
4340	0.00	4340	0.06
4100	0.02	4200	0.07
H	0.04	4100	0.05
		4000	0.00

We see therefore that in this case the spectrogram is as much as three times longer than with the thirty-inch refractor, and this depends only upon the fact that the diameters of the circles of chromatic aberration are almost constant. It is to be noted here that one-half as long an exposure is necessary to secure a measurable spectrogram of a star of magnitude 3.5 with the thirty-inch as with the photographic telescope. According to the apertures of the two objectives, however, this ratio should be less than one-ninth.

Let us now examine some of the conditions other than optical which affect the performance of the thirty-inch telescope. In general the star-images cannot be said to be worse at Pulkowa than elsewhere, but the air is for the most part insufficiently transparent,—a matter of great importance for the ultra-violet end of the spectrum. On this account the spectrum is considerably weakened even in the region of $H\gamma$. That this is not in any great degree to be attributed to the glass is seen from the fact that there are nights (in Spring) on which the spectrum of a star extends to λ 4270. On other evenings (and such are the majority) the continuous spectrum of one and the same star is much fainter even on the violet edge of $H\gamma$ than on the red edge, so that a systematic error will affect the settings upon this line. In most cases the strongest part of the spectrum is in the region λ 4400–4300, while judging from the diameters of the circles of aberration the intensity should be symmetrical on both sides of

the smallest circle. For this reason the region mentioned is for us the most effective with stars of Class II, the prisms being set at minimum deviation for these rays, and the lines of the iron spectrum at $\lambda 4405$ and $\lambda 4415$ being used for comparison.

With the photographic telescope the atmospheric absorption is much less felt; the spectra of stars of Class IIa–IIIa suffer chiefly, but not nearly as much as with the thirty-inch.

Let us now more closely examine the mechanical arrangements of the great refractor, as they are of much importance in setting and retaining the star-image upon the slit ($0^{mm}.03$ wide). Great inconvenience arises from the unavoidable fact that so long and massive a tube cannot perfectly obey the slow-motions in right ascension and declination,—and here again the mechanism of the photographic telescope has a decided advantage. To illustrate the difficulty of setting and retaining the star-image upon the slit, I may say that the two components of γ Virginis are very easily confused during the exposure. The observer is continually in doubt as to which component is upon the slit, as the slightest turning of the declination slow-motion causes the image to suddenly spring away from the slit, while the other component takes its place without permitting the eye to actually notice the transfer. The star-image is displaced from the slit by the very slightest movement, such as a light pressure upon the eye-end of the telescope tube (not upon the spectrograph itself). It is also very difficult to keep the image within narrow limits in the length of the slit (which is parallel to the diurnal motion), particularly when there is any wind, and hence the spectrum is always broader than is necessary for the measurements, with a corresponding loss in the intensity of the spectrogram. When, further, the fact is recalled that in the focal plane for $H\gamma$ the visual star-image is a disk of $1^{mm}.8$ diameter, and that the center of this disk (the center furnishes the most intense rays for the spectrogram) is very hard to locate, as seen in the slit, an idea may be gained of the difficulties which arise in making an exposure for a stellar spectrum, and which often wholly spoil the results.

It is indeed possible with the thirty-inch to secure spectra of stars down to the fourth magnitude by an exposure of one hour with a dispersion of two prisms, but this is only true when the atmosphere is very transparent, and the star near the zenith. It is also to be remarked that stars with which this is possible must belong to Class I, or be pure examples of Class IIa (as α Aurigæ). With stars which are in the transition stage between Classes IIa and IIIa (as α Tauri, or α Bootis), it is impossible to go below magnitude 3.5. Even in case of the bright stars, the difference in the time of exposure required for white and for yellow stars is noticeable:—while the spectrograms of α Cygni and α Aurigæ are sufficiently intense after an exposure of five minutes, those of such stars as α Tauri require not less than twenty minutes to produce similar results. In general we may say that stars down to and including magnitude 3.5 are spectrographically accessible to the thirty-inch refractor.

When we think of the results obtained here with the photographic telescope, it is perhaps clear enough that the Pulkowa thirty-inch, with its present accessories, cannot accomplish one-half of what it would be capable with different optical and mechanical arrangements, and under a different sky than that of Pulkowa, as for instance that of Taschkent or Samarkand, but not that of Odessa, the Crimea, or any stations near the sea.

PULKOWA, RUSSIA,
February, 1895.

NOTE ON THE SPECTRUM OF ARGON.[1]

By H. F. NEWALL.

IN the course of a spectroscopic investigation in which I have been for some time past engaged, a line spectrum, which so far as I was able to make out was unknown, has frequently presented itself upon my photographs. It appeared in May and June, 1894, under conditions which led me to call it, for the sake of convenience, "the low-pressure spectrum." After their announcement at the Oxford meeting of the British Association, it seemed for many reasons natural to borrow the first letter of Lord Rayleigh's and Professor Ramsay's names to give to the unknown lines and in the measurements of the photographs which showed the lines well, there appears an "R" against seventeen lines out of sixty-one measured, the remaining lines being known to belong to Hg, H, N, and nitrocarbons. It transpires now, as I learnt from reading the abstract of the paper in which Lord Rayleigh and Professor Ramsay describe their consummate researches on argon, that the symbol "A" should have been used instead of "R" to designate the lines on my photographs. For the lines are Argon lines.

The conditions under which the spectrum of argon has appeared in my investigations are of interest at the present time, and I hope a description of them may not be unacceptable.

A glass bulb was sealed hermetically to a mercury pump of the Hagen-Töpler form, in which there was strong sulphuric acid floating on the surface of the mercury. The bulb was exhausted as low as possible and refilled with air. The pressure was reduced to about 180 **M**illionths of an atmosphere ($= 0^{mm}.14$), at which pressure a bright discharge could be passed through the residual gases by means of Professor J. J. Thomson's method of surrounding the bulb by a coil of wire, which carries a very rapidly alternating current produced by the discharge of a condenser.

[1] Read before the Royal Society.

The discharge was passed for thirty minutes, during which time a photograph of the spectrum was taken. The pressure of the gas in the bulb fell during the passage of the discharge from the value 174 **M** ($= 0^{mm}.13$) to 112 **M** ($= 0^{mm}.085$). The spectrum shows the bands of nitrogen strong, also mercury lines and nitrocarbon groups strong, hydrogen weak, no oxygen or argon.

Again the discharge was passed for thirty minutes and a new photograph was taken. The pressure fell from 100 **M** ($= 0^{mm}.076$) to 20 **M** ($= 0^{mm}.015$); the nitrogen spectrum had faded considerably, and there had appeared a number of fine lines which I was unable, in spite of careful efforts, to identify with the lines of any known substances.

The nature of my method of investigation of spectra is such that it is not difficult to pick out of the numerous spectra which appear superposed on the photographic plate the lines which belong to any one spectrum.

The results of measurements made in the last few days of seventy-two lines in my "low-pressure spectrum" are given below, and side by side are given the measurements of the wave-lengths determined by Mr. Crookes for the argon lines.

The agreement of the measurements shows conclusively that we have been measuring the same spectrum. Between $H\gamma$ and $\lambda 3700$ the agreement is all that we could hope for, taking into account the fact that my measurements were not made with a view of giving a final and carefully considered set of measurements of wave-lengths, but between $H\gamma$ and $H\beta$ there is a systematic difference of about three tenth-meters, which I am unable at present to account for. The agreement of grouping and intensity, however, leaves no doubt as to the identity of the spectrum of my low-pressure lines with the spectrum of argon. I have reduced my measurements with reference to Rowland's scale of wave-lengths, and I infer from the value adopted for the $H\beta$ (F) line, that Ångström's scale has been used in Mr. Crookes' reduction. The difference between the scales is not enough to account for the discrepancies above referred to.

H. F. Newall		William Crookes January 24, 1895			
Measurements of Lines on Photograph		The Two Spectra of Argon			
		Blue		Red	
Wave-length	Intensity	Wave-length	Intensity	Wave-length	Intensity
3719.2	2	371.80	4		
3730.0	8	372.98	10		
3738.8	3	373.85	3		
3750.2	3				
3766.1	5	376.60	8		
		377.05	2		
3781.8	6	378.08	9	377.15	1
		379.95	1		
		380.35	1		
3809.8	4	380.95	4		
3827.0	—	382.75	2		
		383.55	2	383.55	3
		384.55	1		
3850.8	7	385.15	10		
3868.1	6	386.85	8		
		387.18	2		
3873.4	4	387.55	2		
3883.2	5	389.20	5		
3892.2?	—			390.45	8
		391.50	1		
3918.8	5				
		392.75	3		
3920.3	6				
3928.2	8	392.85	9		
3930.8	3	393.18	3		
3932.3	5				
3944.1	5	394.35	3		
		394.85	9	394.85	10
3968.0	7	396.78	3		
3973.0	4				
3979.2	3	397.85	1		
3991.3	4				
3994.8	6				
4013.8	8	401.30	8		
4033.7	3	403.30	1		
4035.0	2				
4038.2	5				
4042.7	5	404.40	8	404.40	9
4069.7	2				
4072.4	9	407.25	8		
4075.8	3				
4082.2	4				
4104.2	8	410.50	8		
4130.9	6	413.15	3		
4155.8				415.65	6

H. F. Newall		William Crookes January 24, 1895			
Measurements of Lines on Photograph		The Two Spectra of Argon			
		Blue		Red	
Wave-length	Intensity	Wave-length	Intensity	Wave-length	Intensity
CN group has, though only of intensity 5, obliterated this set of lines.		415.95	10	415.95	10
		416.45	·8	416.45	4
		418.30	8	418.30	8
		419.15	9	419.15	9
		419.80	9	419.80	9
		420.10	10	420.10	10
4227.5	8	422.85	6		
		425.15	2	425.15	3
		425.95	8	425.95	9
4266.4	9 ? N	426.60	6	426.60	4
		427.20	7	427.20	8
4277.4	8 ? N	427.70	3		
4282.1	6				
4299.4	4	429.90	9		
4308.7	4			430.05	9
4330.8	10	433.35	9	433.35	9
4336.0	2			434.50	5
4351.4	7	434.85	10		
4370.4	8	436.90	9		
4375.8	3				
4379.8	8	437.65	9		
4400.1	5				
4401.7	9	439.95	10		
4414.1	4				
4421.2	4				
4426.0	10	442.25	10		
4431.3	10	442.65	10		
4460.0	2				
4482.2	6	447.83	6		
		450.95	8	450.95	9
				451.40	2
4546.5	7	454.35	7		
4581.2	6	457.95	6		
		458.69	6		
4592.0	8			459.45	2
4611.0	9	460.80	8		
4632.1	4			462.95	5
4639.0	2				
4644.0	1				
4659.6	7	465.65	5		
				470.12	8
4729.4	6	472.66	2		
4738.0	8	473.45	6		
4766.6	5	476.30	1		
4808.0	9	480.50	7		
4847.2	5	484.75	1		
4879.8	5	487.9	10	487.9	4

The experiments were repeated, with slight variations, several times with results which, so far as the spectrum of argon is concerned, were constant. But it was noted that continued passage of the discharge appears to result in the attaining of a certain minimum pressure, after which there is slight and slow rise to a tolerably fixed pressure. It is not necessary to dwell on these points in the present note.

It is interesting to find argon asserting itself, unsolicited, in quite new circumstances, and under conditions which practically constitute one more mode of separating argon from nitrogen—namely, the getting rid of nitrogen by passing an electric discharge through it in the presence of hydrogen or moisture and acid.

THE OBSERVATORY, CAMBRIDGE,
February 14, 1895.

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. V.

By Henry A. Rowland.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4414.621		00	4420.832		00
4414.714	Zr	00	4421.090		000
4414.896		000	4421.290		00 N
4415.047	Mn	2	4421.495		00
4415.199		000 N	4421.616		00
4415.293 s	Fe	8	4421.733	V	0
4415.414		000 N	4421.928	Ti	00
4415.586		000	4422.104		1
4415.722		3	4422.226		0
4415.945		00 N	4422.461		00 N d?
4416.074		000	4422.666		00
4416.224		00	4422.741	Fe, Y	3
4416.319		00	4422.872		000
4416.517		00 N	4422.985	Ti	0
4416.636	V	0	4423.134		0 d?
4416.811		00 N	4423.298	Fe	1
4416.985		2	4423.430	Cr	0 N
4417.163		000	4423.630		000
4417.275		00 N	4423.747		000
4417.450	Ti	0	4423.843		000
4417.577	Co	00	4424.006	Fe?-	2
4417.740		00	4424.233		0
4417.884	Ti-	3	4424.368		00
4418.044		000	4424.457	Cr	0
4418.199		00 N	4424.531		00
4418.366		000	4424.748		0 N d?
4418.499	Ti-	1	4424.975		00 N d?
4418.590		00	4425.321		000 N
4418.734		00 d?	4425.608 s	Ca	4
4418.944		00 N	4425.827		00
4419.106		00 N	4425.931		00 N
4419.265		00 N	4426.121		000
4419.440		00 N	4426.201	Ti	0 N d?
4419.675		00	4426.536		000
4419.768		000	4426.617		000
4419.944	Mn	00 N	4426.839		000 Nd?
4420.100	V	00 N	4427.054		000 Nd?
4420.266		00 N	4427.266	Ti	2
4420.447		0	4427.482	Fe	5
4420.686	Zr	00	4427.623		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4427.760	La	000	4436.000		0000
4427.875	La	0000	4436.162		000 N
4428.083		00 N	4436.313	V	0
4428.256		00 N	4436.516	Mn	2
4428.438		00 N	4436.750		00
4428.711	V-Cr	1 d?	4436.852		00
4428.873		00	4436.949		00
4429.077		000	4437.112	Fe-Ni	2 d?
4429.366		00	4437.297		000 N
4429.456		00	4437.429		000 N
4429.664		000 N	4437.589		000 N
4429.804		000 N	4437.729		0
4429.958	V	00	4437.862		00
4430.070	La	00 N	4438.006	V	0
4430.221	La	00 N	4438.192		00
4430.356	Fe	1	4438.359	Sr, Zr, Ti	00 Nd?
4430.524		00	4438.510	Fe	1
4430.646		00	4438.687		00 N
4430.785	Fe	3	4438.790		00
4430.929		0	4438.953		0000
4431.302		0 N	4439.127		0000
4431.453		000	4439.332		0 N d?
4431.525		0	4439.521		00
4431.660		000	4439.649		0000
4431.785		00	4439.806		0
4432.009		0	4439.911		000
4432.247		00	4440.054	Fe	1
4432.330	Cr	0	4440.231		000 N
4432.477		0000	4440.342	Fe	00 Nd?
4432.587		000	4440.515	Ti	00
4432.736	Fe	1	4440.635	Zr-	1
4432.904		00 N	4440.787		00 N
4433.089		000 N	4440.989		1
4433.208		00 N	4441.151	Fe	0
4433.390	Fe	3	4441.255		0
4433.554		00	4441.433	Ti	00
4433.742		00 N	4441.591		00
4433.948	Fe	1	4441.718		00
4434.057		000	4441.881	V-	3 N d?
4434.168	Ti	0 N d?	4442.127		00 N
4434.361		000 N	4442.241		000
4434.504		00	4442.421		000
4434.605		0	4442.510	Fe	6
4434.810		00 N	4442.579		000
4434.918		000	4442.751		0000
4435.129 s	Ca	5	4442.842		000
4435.321	Fe	2	4442.996	Fe	1
4435.493		00 N	4443.161	Zr	0
4435.605		00 N	4443.365	Fe	3
4435.851 s	Ca	4	4443.459		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4443.723		000 N	4452.903		00
4443.976	Ti	5	4452.967		00
4444.133		0000	4453.171	Mn	1
4444.243		000	4453.328		00
4444.385		0	4453.486	Ti	2
4444.566	V-Ti	00	4453.692		00 N
4444.728	Fe, Ti	2	4453.876	Ti	1
4444.862		00	4454.004		000
4445.228		000 N d?	4454.164		000
4445.479		000 N	4454.274		000
4445.641	Fe	1	4454.387		000
4445.844		00 N d?	4454.552	Fe	3
4446.019		000 N	4454.700		000
4446.238		0000 N	4454.836		00
4446.409		00	4454.953 s	Ca, Zr	5
4446.566		00	4455.193	Mn	1
4446.704		0000	4455.342		000
4446.795		000	4455.485	Mn, Ti	2
4447.008	Fe	2	4455.615		000 N
4447.052		0000	4455.710		000 N
4447.190		0000	4455.815		000 N
4447.302	Mn, Fe	2	4455.980	Mn	2
4447.519		00 N d?	4456.064 s	Ca	3
4447.718		000 N	4456.225		000
4447.892 s	Fe	6	4456.338		000
4447.952		00	4456.497	Fe	1
4448.184		000 N	4456.625		000 N
4448.455		000 N	4456.794 s	Ca	2
4448.607		000 N	4456.945		000
4449.111		00 N	4457.040		000
4449.313	Ti	2	4457.207	Mn	0
4449.507		00	4457.330		000
4449.630		00	4457.435		00
4449.882		00	4457.600	Ti, V, Zr	2
4450.093		00 N d?	4457.712	Mn	2
4450.267		00 N	4457.835		0000
4450.398		000	4457.940	V	00 N
4450.482	Zr-Fe	1	4458.110		000
4450.654	Ti?	2	4458.239	Fe ?	2
4450.794		000	4458.409	Mn	2
4450.925		00	4458.550		000
4451.087	Ti	1	4458.690	Cr	0
4451.279		000 N	4458.850		000
4451.521		000 N d?	4459.003		00 N
4451.752	Mn	3	4459.199	Ni	2
4451.997		000 N	4459.301	Fe	3
4452.171	V	0 N	4459.525	Fe, Cr	1
4452.311		0000	4459.670		000 N
4452.488		000	4459.779		000
4452.782		0	4459.922	V	1

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4460.063		000	4467.017		000
4460.164		000 N	4467.102	Co-Zr	1
4460.276		000	4467.248		000
4460.389	V	0	4467.373		000
4460.462	Mn	1	4467.498		00
4460.525		0	4467.603		0000
4460.700		00 N d?	4467.721	Cr	00 N
4460.944		00	4467.997		00 Nd?
4461.093		000 N	4468.160		00 N
4461.242	Mn	1	4468.317		000 N
4461.365	Fe, Zr, Ni	1	4468.463		00 N
4461.545	Fe	0	4468.663	Ti-	5
4461.592		00	4468.800		000
4461.818	Fe	4	4468.914		000 N
4461.983		000 N	4469.150		00 N
4462.165	Fe-Mn	3 N d?	4469.316	Ti	1
4462.365		0	4469.441		0000
4462.525	V	00	4469.545	Fe	4
4462.621	Ni	1	4469.731	Co	0 d?
4462.750		0000	4469.873	V	00
4462.860		00	4469.971		0000
4462.933		00	4470.100		000
4463.060		000	4470.300	Mn	1
4463.152		00	4470.477		000 N
4463.300		00	4470.648	Ni-Zr	2
4463.425		00 N	4470.799		000
4463.569	Ti-Ni	0	4470.875		000
4463.698		00	4471.017	Ti-	1
4463.843	Ti	0000	4471.166		000
4463.997		0000 N	4471.250		000
4464.138		0000	4471.408	Ti	0
4464.389		000	4471.571		000
4464.503		000	4471.724		00 N
4464.617	Ti?	2	4471.846		0
4464.844	Mn	2	4471.971		00
4464.938		1	4472.076		0000
4465.069		00	4472.241		000
4465.143		00	4472.371		000
4465.295		00 N	4472.578		00 N
4465.385		000 N	4472.705		00 N
4465.519	Cr	0	4472.884	Fe	1
4465.667		000	4472.967	Mn	0
4465.775		00 N	4473.095	Ni?	0
4465.975	Ti	1	4473.300		000
4466.147		00 N	4473.385		000
4466.333		00 N	4473.550		000
4466.415		000	4473.633		000
4466.548	Ni	0	4473.798		000
4466.727	Fe	5	4473.927		00
4466.886		000	4474.001		00

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4474.213		00	4482.170		000 N
4474.333		000	4482.338	—, Fe	5
4474.566		00	4482.438	Fe	3
4474.737		00	4482.603		0000
4474.912		00	4482.704		000 N
4475.026	Ti	0	4482.904	Ti-Fe	1
4475.175		000	4483.039	Cr	00
4475.260		000	4483.193		0000
4475.335		0000	4483.346		0000
4475.470	Cr	00	4483.513		0000
4475.633		000 N	4483.706		0000
4475.886		000 N	4483.825		0000
4476.185	Fe	4	4483.942		0
4476.253	Ag	3	4484.078	Co	0
4476.399		0000	4484.250		000
4476.596		000	4484.392	Fe	4
4476.804		000	4484.555		000
4477.028		000	4484.667		00
4477.228		00	4484.859		000
4477.397		000 Nd?	4484.993		000
4477.635		00 N	4485.122		000
4477.810		000 Nd?	4485.244		000
4478.015		000 N	4485.373		000
4478.190		0	4485.586		000
4478.306		000	4485.701		000
4478.486	Fe-Co	00 N	4485.846	Fe	3
4478.792		00 N	4486.003		000
4478.982		00 N	4486.140		0
4479.163		00 N	4486.286		000 N
4479.404		00	4486.387		000 N
4479.553	Mn	0	4486.488		000 N
4479.775	Fe	1	4486.762		00 N
4479.879	Ti	00	4486.914		000
4480.015		000 N	4487.076		0
4480.133		0	4487.168		00
4480.308	Fe	1	4487.420		00
4480.440		00	4487.530		00
4480.548		000	4487.685		00
4480.633		0000	4487.916		0
4480.752	Ti, Ni	0 N	4488.034		00
4480.868		0000	4488.108		000
4480.990		0	4488.218	Fe-Cr	0
4481.195		00	4488.305		1
4481.298		0	4488.493		1
4481.438	Ti	1	4488.687		000 N
4481.515		0	4488.852		000
4481.647		0000 N	4488.928	V	0000
4481.782	Fe	1	4489.075	Fe	1
4481.940		000 N	4489.262	Ti	0
4482.078		000 N	4489.351		2

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4489.505		00	4497.268		000
4489.630	Cr	0	4497.429		000
4489.766		00	4497.571		000
4489.911	Fe	4	4497 842	Ti	0 N
4490.092		000	4498.030		000
4490.253	Mn-Fe	3 N	4498.265		000
4490.398		00	4498.467		00 N
4490.561		000	4498.725		00 N
4490.701	Ni	0	4498.897	Cr	0
4490.778		00	4499.066 s	Mn	1
4490.942	Fe	2	4499.201		0000
4490.975		0	4499.310 s		1
4491.113		0000	4499.525		000 N
4491.272		000	4499.666		000
4491.377		000	4499.881		0000
4491.570		2	4500.122	Mn	000
4491.823	Cr-Mn	0	4500.451	Cr	0
4492.016	Cr	00	4500.537		00
4492.139		000	4500.669		000
4492.278		000	4500.807		00
4492.475	Cr, Fe	0	4500.932		000
4492.700		00	4501.114		000
4492.846		1	4501.264	Cr, Mn	0
4493.016	-	0000	4501.448 s	Ti,-	5
4493.132		000	4501.622		00 N
4493.391		000	4501.813		00 N
4493.543		00	4501.946		0 N d?
4493.695		1	4502.157		00 N
4493.917		00 N d?	4502.217		0000
4494.118		0	4502.388	Mn	2
4494.222		1	4502.603		00
4494.356		00 N	4502.764	Fe?	0
4494.548		00	4502.925		000
4494.656		00	4503.046		0000
4494.738 s	Fe	6	4503.228		000
4494.903		000	4503.476		000
4495.031		000	4503.519		000
4495.182	Ti	00	4503.654		000
4495.426		00	4503.926		00
4495.590		0 N	4504.042	Mn	00
4495.738		0	4504.224		0000
4495.921		000 N	4504.371		000 N
4496.125		1	4504.707		0000
4496.318	Ti	1	4504.898		00
4496.409		00	4505.003	Fe	1
4496.541		0000	4505.196		00
4496.676	Mn	00 N	4505.404		00 N
4496.826		000	4505.647		0000
4497.023 s	Cr	3	4505.959		00
4497.138	Zr	0	4506.092		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4506.259	Ba?	00 N	4514.358	Fe, Co	1
4506.497		00	4514.486		000
4506.618		000	4514.594		1
4506.776		00	4514.662	Cr	0
4506.907		00	4514.817		000
4507.009		00	4514.957		00 N
4507.139		0000	4515.134		000
4507.266		0000	4515.273		0000
4507.396		0	4515.342		0
4507.560		00	4515.508		3
4507.711		0000	4515.606		00
4507.919		00	4515.763		00 N d?
4508.027		00	4516.037		00 N
4508.177		00	4516.255		000 N
4508.250		00	4516.437		0 N
4508.455 s	Fe?,-	4	4516.628		000
4508.638		000	4516.826		0 N
4508.716		000	4517.094		000 Nd?
4508.855		0	4517.255		000
4509.063		000	4517.321	Co	0
4509.294		000	4517.471		0000
4509.456		0 N	4517.539		000
4509.616		0	4517.702	Fe	3
Ba ?, — 4509.758		000	4517.764		000
4509.904		1	4517.923		000
4510.161		00 N	4518.004		000
4510.344		0000	4518.198	Ti	3
4510.434		0000	4518.349		000
4510.708		000	4518.506		1
4511.000		0	4518.612		00
4511.233		00	4518.753		0
4511.345	In	00	4518.866	Ti	0
4511.516		00 N	4519.027		000
4511.728		00 N	4519.148		000
4512.063	Cr	1	4519.465		000
4512.227		00 N	4519.624		0000 N
4512.439		0	4519.806		00
4512.602		000	4520.009		00 N
Ca ? 4512.663		000	4520.157	Ni	0
4512.732		000	4520.282		000
4512.906	Ti	3	4520.397	Fe?,-	3
4513.051		000	4520.565		000
4513.164	Ni	0	4520.701		00 N
4513.385		000 N	4520.970		00 N
4513.491		000	4521.132		000 N
4513.603		0	4521.304	Cr	0
4513.754		00	4521.446		000
4513.886		00	4521.598		000
4514.038		0000	4521.834		000 N
4514.078		000	4522.053		00 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4522.195		00	4529.849	Fe	1
4522.286		00	4530.020	Cr	0
4522.418	La	0000	4530.172		000 N
4522.539		00	4530.275		000 N
4522.691	Fe?	0	4530.506		000 N
4522.802		3	4530.668		00 N
4522.974	Ti	2	4530.866	Cr	0
4523.116		000	4530.910	Cr	1
4523.250		0	4531.123	Fe?, Co	2
4523.412		000 N	4531.327	Fe	5
4523.572	Mn?	1	4531.518		0000
4523.751		000 N	4531.625		0000
4523.910		000 N	4531.801	Fe	2
4524.090		00	4531.974		0000
4524.262		00	4532.075		000
4524.393		00	4532.306		000
4524.584		0000	4532.485		000 N
4524.685		0000	4532.743		000 N
4524.856		0	4532.944		00
4525.009		00	4533.133		1
4525.110		0	4533.219		0
4525.314	Fe	5	4533.419	Ti	4
4525.412		000	4533.583		0000
4525.783		000 N	4533.710		000 N
4526.031		0	4533.887		00 N
4526.269	Cr	0	4534.139	Ti-Co	6
4526.431		000	4534.340		1
4526.579		1	4534.484		000
4526.632	Cr	2	4534.646		000
4526.732	Fe	1	4534.788		000
4526.887		0000	4534.953	Ti	4
4526.955		0000	4535.152		000 Nd?
4527.101	Ca?	3	4535.310	Cr	0
4527.332		000 N	4535.491		00
4527.490	Ti	3	4535.615		000
4527.632		0	4535.741	Ti	3
4527.807		000	4535.879	Cr	1
4527.954		0	4535.909	Zr	0
4528.097		000 N	4536.094	Ti	2
4528.310		00 N	4536.222	Ti	2
4528.473		000 N	4536.377		0000
4528.647		0 N	4536.532		00
4528.798	Fe	8	4536.675		00
4528.929		0	4536.853		0000
4528.990		0	4537.075		000
4529.185		000	4537.389		00 N
4529.394		000	4537.592		00
4529.482		000	4537.845		0
4529.656		1	4537.986		000
4529.728		1	4538.138		00 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4538.351		000 N	4545.861		000
4538.539		00	4545.983		000
4538.634		000	4546.129	Fe, Cr	3
4538.770		00 N	4546.276		000
4538.928	Fe	0	4546.428		000 N
4539.013	Fe	0	4546.645		00
4539.124		00	4546.848		00
4539.263		00	4546.975		0000
4539.424		00	4547.101	Ni	1
4539.565		000 N d?	4547.192	Fe	2
4539.759		00	4547.401	Ni	0
4539.946	Cr	0 N	4547.587		000
4540.167		00 N	4547.675		000
4540.385		00	4547.815		000 N
4540.446		0000	4548.024	Fe	3
4540.575		00	4548.165		0000
4540.672	Cr	2	4548.301		00
4540.880	Cr	2	4548.412		000
4541.043		00	4548.614		00
4541.236	Cr	0	4548.756		00
4541.352		000	4548.938	Ti	2
4541.483		0	4549.069		000
4541.690	Cr	2	4549.187		000
4541.823		000	4549.273		000
4541.976		000	4549.360		00
4542.113		00	4549 450		00
4542.234		000	4549.642	Fe	2
4542.400	Zr	0 N	4549.808	Ti-Co	6 d?
4542.600	Fe	1 N	4549.990		0
4542.785	Cr	0	4550.162		000 N
4542.876		0	4550.293		0
4543.012		0000	4550.445		00
4543.202		000	4550.601		000
4543.402		00	4550.743		000
4543.525		0000	4550.942	Fe?	2
4543.900		00	4551.139		000
4543.990	Co	0	4551.261		000
4544.190		1	4551.399	Ni	0
4544.365		000	4551.458		000
4544.444		0000	4551.691		000 N
4544.655		00 N	4551.824		0
4544.788	Cr	1	4552.018		00 N d?
4544.864	Ti	3	4552.314		0
4545.008		00	4552.460		0
4545.142		00 N	4552.632	Ti	2
4545.311		1	4552.725	Fe	1
4545.507	Cr-V	0	4552.824		000
4545.568		00	4553.065		000 N
4545.713		000	4553.219		00
4545.770		000	4553.346	Ni	0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4553.546		000 N d?	4562.541		0
4553.796		0000 N	4562.649		0000
4554.009		0000	4562.814	Ti	00
4554.211[1] s	Ba	8	4563.059		000 N
4554.423		0000	4563.413		00
4554.484		0000	4563.599	Ti	00
4554.626		1	4563.939 s	Ti	4
4554.707		000	4564.069		00
4554.869		000 N	4564.203		0000
4555.007		00	4564.352		00 d
4555.162	Cr	2	4564.511		00
4555.264		00	4564.629		0000
4555.468		00 N	4564.750		00
4555.662	Ti	3	4564.875		0
4555.830		000	4565.002	Fe	0
4555.910		00	4565.215		000 N
4556.063		3	4565.296		00 N
4556.306	Fe-Cr	4	4565.488	Fe	0
4556.549		0000 N	4565.597		00
4556.719		0000 N	4565.688	Cr	3
4556.934		0000 N	4565.842	Co-Fe	2
4557.107		0	4565.905		00
4557.262		000	4566.031		000
4557.457		0 N	4566.198		00 N
4557.689		0000 N	4566.414		00 N
4557.927		00	4566.555		0000
4558.060		00	4566.693	Fe	1
4558.162		0000	4566.834		0000
4558.285		0	4567.046	Fe	1
4558.402		00	4567.168		00
4558.640		00	4567.345		0000
4558.827	Cr?	3	4567.391		0000
4558.949		000	4567.584		00 N
4559.106		0000	4567.755		000
4559.526		0000	4567.917		0000
4559.728		0000	4568.221		0000
4559.980		0000	4568.499		0
4560.102	Ni, Ti	0	4568.777		00
4560.266	Fe	2	4568.940	Fe	1
4560.457		00	4569.034		0
4560.589		00	4569.243		00 N
4560.740		000	4569.425		000 N
4560.892		00	4569.536		00 N
4561.044		00	4569.693	Cr	00
4561.145		00	4569.788	Cr	0
4561.368		00 N	4569.992		0000 N
4561.591		1	4570.199		00 N
4561.909		00 N	4570.559		000 N
4562.148		0000 N	4570.781		000 Nd?
4562.406		0000	4571.095		00 N

[1] This line is either double or reversed in the Sun. The Ba line seems to coincide with the center.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4571.275 s	Mg	5	4580.080		000
4571.470		000 N d?	4580.228	Cr	3
4571.618		0	4580.326		0000
4571.720		0000	4580.463		000
4571.849	Cr	1	4580.590	V	1
4571.976		00	4580.762	Fe-Ni	1
4572.156 s	Ti-	6	4580.911		000
4572.366		000	4581.055		00 N
4572.457		00	4581.221		00 N
4572.600		0000	4581.369		0
4572.766		00	4581.575	Ca	4
4573.041		0 N	4581.693	Co, Fe	4
4573.231		0000	4581.805		00 N
4573.828		0000	4582.007		000 Nd?
4573.960	Ba?	000	4582.250		000 Nd?
4574.168		00	4582.483		0 N
4574.396	Fe	1	4582.683		00 N
4574.537		0000	4582.851		000 N
4574.658		00 N	4583.011		1
4574.739		0000	4583.126		00
4574.899	Fe	2	4583.296		00
4575.075		00 N d?	4583.424		000
4575.286		00	4583.587		0
4575.402		0000	4583.749		00 N
4575.600		00 N	4583.892		00
4575.726	Zr	00 N	4584.018	Fe-	4
4575.964		0	4584.168		00
4576.096		0000	4584.269		00
4576.268		000 N d?	4584.447		00 N
4576.512		2	4584.618		000
4576.686		00	4584.730		0000
4576.769		000	4584.900	Fe	1
4576.957		000	4585.001		2
4577.181		000 N d?	4585.118		00
4577.356	·V	0	4585.257		00
4577.501		000	4585.368		000
4577.656		000 N	4585.519		0
4577.868		00	4585.772		000
4577.988		000	4585.874		00
4578.220		00 N d?	4586.047	Ca	4
4578.503		00	4586.155		0
4578.732 s	Ca	3	4586.315		00
4578.909	V	00 N	4586.408	Cr	1
4579.062		00 N	4586.552	V	1
4579.231		00 N	4586.716		000
4579.359		000	4586.896		000 N
4579.506		0	4587.169		00
4579.684		00 N d?	4587.308	Fe	2
4579.862	Ba?	00	4587.571		00 N d?
4579.994		0	4587.777		00 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4587.898		00	4596.128	Ni	0
4588.052		000 N	4596.245	Fe	2
4588.180		00 N	4596.414		000
4588.381 s		3	4596.589	Cr-	1
4588.574		00 N	4596.753		00
4588.697		00 N	4596.857		000
4588.859		00	4597.080	Co	0 N
4589.193		00 N	4597.211		00
4589.468		00 N	4597.430		0
4589.686		000	4597.560		0
4589.912		000 N d?	4597.775		000 N
4590.126 s		3	4597.929		1
4590.246		0000	4598.050		1
4590.388		000	4598.186		0000
4590.516		000	4598.303	Fe	3
4590.664		000 N	4598.456		0000
4590.851		000	4598.547		00
4590.965		0	4598.612		00
4591.117		00	4598.792		000
4591.290		00	4598.918		0
4591.421		00	4599.109		000
4591.574	Cr	2	4599.183		00
4591.693		1	4599.408	Ti	00
4591.911		000 N	4599.618		0000
4592.027		00 N	4599.752		000
4592.231	Cr-	1	4600.018	Fe?	2
4592.393		00	4600.145		000
4592.534		00	4600.279	Cr	1
4592.707	Ni	2	4600.383		00 N
4592.840	Fe	4	4600.541	Ni	2
4592.990		0000	4600.737		00 N d?
4593.102		000	4600.932	Cr	3
4593.355		00	4601.114		0
4593.543		000	4601.207	Cr	0
4593.704		1	4601.319		00
4593.883		000	4601.452		00
4594.002		0	4601.557		00
4594.113		0	4601.734		000
4594.297	V	2 N	4601.917		000
4594.459		000 N	4602.013		000
4594.590		00 N d?	4602.183 s	Fe	3
4594.820	Co	00 N	4602.356		0000
4594.964		0000	4602.565		0000
4595.067	Ni	0	4602.717		0000
4595.227		00	4602.929		0000
4595.386		00	4603.126	Fe	6
4595.540	Fe	2	4603.282		000
4595.651		00	4603.525		0
4595.770	Cr	0	4603.665		0000
4595.865		000	4603.799		00

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4603.902		00	4612.794		00
4604.031		0	4612.925		000
4604.137		0	4613.137		00 N
4604.420		00 N	4613.386	Fe	3
4604.580		0000	4613.544	Cr, La	3
4604.735	Fe ?	2	4613.738		000 Nd?
4604.863		000	4613.892		00
4605.025		00	4614.097		1
4605.171	Ni	3	4614.388	Fe ?	1
4605.278		000	4614.529		0000
4605.430		000 N	4614.713		00
4605.536	Mn	0	4614.761		00
4605.640		00	4614.914		00
4605.769		2	4615.114		0000 N
4606.017		00 N	4615.427		0000 N
4606.189		000 N	4615.632		000
4606.404	Ni,C	2	4615.743	Fe ?	1
4606.574		00 N	4615.896		00
4606.687		000 N	4616.114		00
4606.969		000 N	4616.305	Cr	4
4607.274		00 N	4616.472		000
4607.394		0000	4616.644		00 N
4607.510 s	Sr	1	4616.804		1 N
4607.687		000 N	4616.923		000
4607.831	Fe	4	4617.134		000
4608.037		000	4617.244		000 N
4608.305		000	4617.452	Ti	3
4608.406		0000	4617.636		000 N
4608 700		000 N d?	4618.046		00
4608.887		00 N	4618.150		00
4609.023		0000 N	4618.303		0000
4609.447		0	4618.536		00
4609.540		000	4618.688		00
4609.752		0000 N	4618.971	Fe-	4 d?
4609.833		000 N	4619.133		000 N
4610.088		0	4619.285		00 N
4610.267		0000	4619.468	Fe	3
4610.365		0	4619.607		0000
4610.771		000 N	4619.711	Cr	1
4611.118		000	4619.852		0000
4611.249		00	4619.963		00
4611.368 } s	Cr	0	4620.072		0000
4611.469 }	Fe	5	4620.313		00
4611.664		000	4620.522		00 N
4611.816		00	4620.693	Fe	1
4612.000		000	4620.986		000 N
4612.138	Cr	00	4621.208		0000
4612.251		000	4621.299		000
4612.446		000	4621.482		0000 N
4612.646		000	4621.654		00

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4621.795		00	4630.306	Fe	4
4621.947		000	4630.582		000 N
4622.065	Cr	0	4630.740		0
4622.128	Cr	1	4630.958		00 N
4622.307		000 N	4631.212		0 N
4622.433		000 N	4631.385		000
4622.627	Cr	1	4631.512		0000
4622.733		000	4631.663		0
4622.929	Cr	0	4631.900		00 N d?
4623.071		000	4632.129		00 N d?
4623.279	Ti	2	4632.320	Cr	0
4623.476		00 N	4632.503		00 N
4623.759		0	4632.654		00 N
4624.053		000 N	4632.825		00 N
4624.265		00	4632.991		1
4624.443		000 N	4633.100	Fe	4
4624.594		00 N	4633.272		00 N d?
4624.741		00 N	4633.432	Cr	0
4624.923		00 N	4633.555		000 N
4625.074		00 N	4633.722		00 N
4625.227	Fe	5	4633.950		0 N
4625.378		000 N	4634.187		0000
4625.489		00 N	4634.254		2
4625.613		00 N	4634.441		000
4625.947		00 N	4634.547		000
4626.096	Cr	0 N	4634.780		000
4626.198		000	4634.895	Fe ?	1
4626.358	Cr	5	4635.048		00
4626.532		00 N	4635.210		000
4626.718	Mn	0	4635.352	V	00 N
4626.825		000	4635.489		0
4626.975		00	4635.598		0000
4627.190		000 N	4635.736		00
4627.392		00 N	4635.803		0
4627.547		0	4635.884		0000
4627.726		0	4636.027	Fe	2
4627.829		0000	4636.192		000 N
4628.032		0000	4636.339		00 N
4628.197		0000	4636.501		0
4628.335		0	4636.740		0000
4628.448		0000	4636.851		00
4628.637	Cr	00	4637.108		000
4628.860		00	4637.221		00
4629.092		00 N	4637.352	Cr	0
4629.248		00	4637.474		00
4629.521 s	Ti-Co	6	4637.685 s	Fe	5
4629.714		00 N	4637.845		0000
4629.844		000	4637.938	Cr	0
4629.979		00	4638.050	Ti	00
4630.125		000 N d?	4638.193 s	Fe	4

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4638.709		00	4648.835 s	Ni	4
4638.879		00 N	4649.031	Cr	00
4639.132		0	4649.124		00
4639.353		00 N	4649.337		00 N
4639.538	Ti	2	4649.476		000
4639.679	Cr	0	4649.613	Cr	0
4639.846	Ti	2	4649.819		0 N d?
4640.119	Ti	1	4649.992		0
4640.280		000	4650.193	Ti	0
4640.468		1	4650.296		000
4640.681		00	4650.488		0
4640.883		0000	4650.725		00
4641.147		00 N d?	4650.985		00
4641.390		0	4651.121		00
4641.693		000 N d?	4651.290		00
4641.851		000	4651.461	Cr	4
4642.179		00	4651.685		0000 N
4642.306		00	4652.045		0000 N
4642.424		00	4652.198		0000
4642.765		00 N	4652.343	Cr	5
4643.005		00	4652.447		0000
4643.235		000 N	4653.069		0000
4643.389		00	4653.216		0000
4643.475		00	4653.323		0000
4643.645 s	Fe	4	4653.485		000
4643.912		00 N	4653.551		00
4644.066		000 N	4653.677		00
4644.572		00 N d?	4653.819		000
4644.703		00	4653.960		000
4645.368	Ti	0	4654.077		000
4645.483		000	4654.218		000
4645.671		0 N	4654.327		0
4645.819		000 N	4654.478		00 N
4645.965		00	4654.672	Fe	4
4646.058		000	4654.800	Fe	5
4646.168		000	4654.912	Cr	00
4646.347	Cr	5	4655.419		00 N
4646.552		0	4655.634		000 Nd?
4646.676	Cr	00	4655.832		0
4646.815		1	4655.967	Ti	0
4646.962	Cr	0	4656.127		0000
4647.145		000 N	4656.228	Ti	0
4647.354		00	4656.365	Cr	0
4647.454		0	4656.481		000
4647.617	Fe	4	4656.644	Ti	3
4647.876		000 N	4656.815		000
4648.135		1	4656.992		000
4648.297	Cr	0	4657.154		1
4648.497		000	4657.380	Ti?	2
4648.591		000	4657.554		00

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4657.625		000	4666.655	Cr	1
4657.766		1	4666.782		0
4658.034		00 N	4666.925		1
4658.217		000	4667.066		00 N
4658.343		0000	4667.159	Ni	1
4658.475		0	4667.339	Cr	00
4658.675		00 N	4667.424		0
4658.827		00 N	4667.626	Fe	4
4659.054		00 N d?	4667.768	Ti	3
4659.338		000 N d?	4667.941	Ni	1
4659.547		000 N	4668.099		000
4659.707		000 N	4668.243 } s		2
4659.940		0000 N	4668.331	Fe	4
4660.145		00 N	4668.550		00 N
4660.247		00 N	4668.749		1 N
4660.412		00	4669.017		000 N
4660.602		0	4669.164		000 N
4660.801		000	4669.354	Fe	3
4660.902		00	4669.504	Cr	1
4661.083		0	4669.568		000
4661.327		00 N	4669.700		000
4661.507		00 N	4669.829		00
4661.712		1	4670.001		000 N
4661.965		00 N	4670.155		000 N
4662.149	Fe?	1	4670.346	Ni	1
4662.278		000	4670.590		2
4662.390		0000	4670.732		00
4662.496		0000	4670.915		000
4662.693		0	4671.080		00
4662.930		0 N	4671.222		00
4663.354		0	4671.388		000
4663.492	Cr	1	4671.601		1
4663.587	Co	0	4671.742		00
4663.734		000	4671.858	Mn	0
4663.882		0	4672.087		000
4663.999	Cr	1	4672.209		00
4664.139		0	4672.370		000
4664.358		00 N	4672.509		3 N
4664.497		00 N	4672.710		000
4664.720		00 N d?	4672.805		000
4664.965	Cr	3	4673.012		1
4665.355		00	4673.144		000
4665.430		000	4673.347	Fe	4
4665.722		00	4673.460		1
4665.852		000	4673.617		00 N
4665.998		000	4673.818		00 N
4666.076	Cr	1	4673.962		00 N
4666.279		0	4674.131		0000
4666.387	Cr	0	4674.275		1 N
4666.526		000	4674.484		0

ON MARTIAN LONGITUDES.

By Percival Lowell.

With the object of constructing a map of the planet, I made, during last October and November, the following series of observations on the longitudes and latitudes of prominent points on the disk of Mars. The observations cover thirty-six points in all, and were taken between October 12 and November 22.

The longitudes were measured with a power of 440 on the micrometer of the 18-inch glass. The longitudinal thread of the micrometer I adjusted parallel to the polar axis of the planet and then noted the instant of the meridian passage of the point to be determined.

Between the eye and the eyepiece I placed yellow glass. The interposition of a piece of suitably tinted glass—deep yellow seems the best, as theoretically it should be, owing to the correction of the glass for light of that color—reduces the size of the spurious disk made by each point of the planetary one, and so steadies the image and draws out the detail. I discovered subsequently that Schiaparelli had made use of this same device.

The latitudes I got by estimating the positions of the points upon the polar axis, at or near the times of meridian passage.

The latitudes are necessarily not so trustworthy as the longitudes. Of the accuracy of the best of the latter the probable errors are witness. The values given are those after all corrections due to the phase have been taken into account. Such correction is not so simple as it might be, owing to the fact that the phase axis and the polar axis did not in general coincide. The amount of the lacking lune had therefore to be calculated, both for differing points on the disk and for different days of observation. The values are given to tenths of a degree, greater accuracy being illusory.

FASTIGIUM ARYN.

	LONG.	WT.
Oct. 12	4°.9	1
15	4°.8	1
16	2°.2	1
17	0°.7	1
Mean	3°.2	
Probable error	±0°.7	

FASTIGIUM ARYN.

Nov. 17	5°.1	1
18	4°.7	1
19	4°.9	1
20	4°.7	1
21	3°.9	¼
22	3°.4	¼
Mean	4°.7	
Probable error	±0°.2	
Mean of both sets weighted according to their probable errors	4°.6	
Probable error	±0°.2	

SOLIS LACUS (center).

Nov. 6	90°.7	1
9	92°.4	1
10	90°.4	3
11	92°.2	3
12	90°.3	3
13	91°.8	3
Mean	91°.3	
Probable error	±0°.3	

PHŒNIX LAKE.

Nov. 5	111°.3	1
6	114°.5	2
9	111°.	1
10	112°.6	2
Mean	112°.8	
Probable error	±0°.5	

BEAK OF THE SIRENS.

	LONG.	WT.
Nov. 4	126°.2	1
9	127°.7	2
10	125°.8	2
Mean	126°.6	
Probable error	±0°.4	

SINUS TITANUM.

Oct. 31	174°.	4
Nov. 2	174°.4	5
3	173°.7	4
4	174°.6	4
5	175°.6	4
Mean	174°.5	
Probable error	±0°.2	

SYRTIS MAJOR.

Oct. 20	291°.1	1
21	293°.	2
Mean	292°.4	
Probable error	±0°.6	

HAMMONIS CORNU.

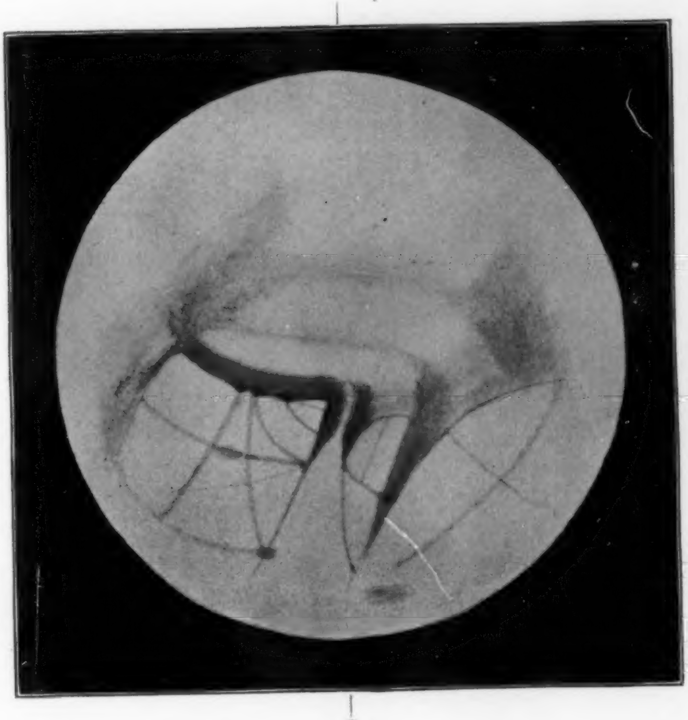
Oct. 19	320°.1	3
21	319°.6	3
Nov. 20	319°.1	3
Mean	319°.6	
Probable error	±0°.2	

EDOM PROMONTORY.

Nov. 17	357°.6	3
18	358°.8	5
19	357°.	2
20	358°.5	3
21	356°.5	4
22	355°.9	2
Mean	357°.6	
Probable error	±0°.3	

PLATE XVIII

N



S

MARS

FASTIGIUM ARYN AT OCTOBER PRESENTATION.

The first fact that emerged from these observations was that all the longitudes as given in Marth's ephemeris were affected by a systematic error of about 5°. In other words the meridian passage with regard to the Earth of any Martian meridian occurred invariably some twenty minutes later than the time set for it to do so by Marth. In Mr. Marth's times all corrections, such as the equation of light, had already been allowed for, and in the observed passages all corrections for phase were, of course, similarly considered. All the data were, therefore, presumably correct, and the discrepancy was unmistakable. All the Martian longitudes were the very palpable amount of twenty minutes behind time.

As early as June, when the first drawings were made here at this opposition, it was evident that something was wrong with the longitudes, as those deduced from Marth's ephemeris for the time at which any given drawing was made did not coincide with those taken from Schiaparelli's chart.

So soon as I began special observations upon the longitudes the cause of the discrepancies became clear. The Fastigium Aryn at its October presentation was the first point I timed, and I found that in spite of errors of observation it never once succeeded in passing the center of the disk as early as the time predicted for it in the ephemeris.

When the Sinus Titanum came round in November, I found it similarly to be behind time. So with other prominent points. Measures of the Fastigium Aryn at the November presentation confirmed the previous tardiness, and showed the amount of the error to be $4^{\circ}.6$ of longitude. This is a discrepancy far transcending the probable error of the observations as deduced from their discussion.

As all the observations are independent, their mutually confirmatory character is conclusive as to their individual trustworthiness, and to their disclosure of some systematic error in the ephemeris.

Reduction of the observations gives for the longitude of the Fastigium Aryn $4^{\circ}.6$; that being the mean of both

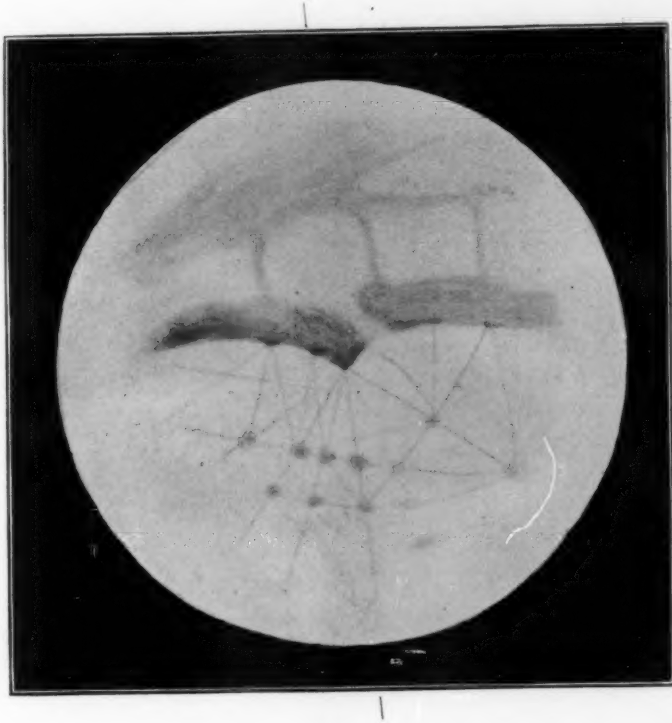
the October and the November determinations, when the mean of each set is weighted according to its own probable error. The probable error of the result is 0°.2.

In order to compare this value of the longitude of the zero meridian with that got by Schiaparelli in 1879, we must take into account the latitudes of the point observed on the two occasions. For the Fastigium Aryn is the tip of a tapering isosceles triangle that projects into the Sabæus Sinus, and the axis of the triangle does not lie due north and south, but is inclined about 15° to the meridian in the direction N. N. E. and S. S. W. The shape of the promontory is thus an entering wedge to some uncertainty. For, owing to the inclination, the longitude of the point measured will depend upon the latitude taken for it. Indeed, at certain seasons, the position of the extremity of the peninsula is further masked by a sort of causeway that makes out southward till it eventually joins Deucalionis Regio, thus cutting the Sabæus Sinus completely in two. The continuation first became evident this year in October. To be sure, therefore, that the same point is measured on different occasions, the latitudes must agree; otherwise some divergence in longitude will result simply from such latitude in the observations. Now, in 1879, the point on the peninsula measured by Schiaparelli lay in N. 1°; this year what was taken as the tip turned out to lie in N. 2°.8. Consequently the two points determined differed in longitude by the difference of latitude, 1°.8, into the sine of 15°, or by 0°.47. Adding this amount to the above 4°.6 we get 5°.1 as the longitude this year of the point of the Fastigium Aryn found by Schiaparelli in 1879 to be in longitude 0°.92. These two amounts are therefore respectively to be subtracted from all the other longitudes in their sets in order to compare the two sets together.

When this is done the following close agreement appears between certain points determined by me this year and the corresponding ones determined in 1879 by Schiaparelli.

PLATE XIX

S



N

MARS

Sinus Titanum at November Presentation

Fastigium Aryn	Ganges	Phœnix Lake	Sinus Titanum
1879 0° - - - - - - -	55°.3	107°.	169°.2
1894 0° - - - - - -	54°.6	107°.7	169°.4

Cimmerium Mare (Mouth of the Æthiops)	Phison (Mouth of)	Euphrates (Mouth of)
1879 239°. - - - - - - - - - -	335°.4	337°.
1894 237°.9 - - - - - - - - - -	334°.3	338°.

It may also be interesting to note how like are the values of the latitude of the Sinus Titanum taken at the same epochs.

Latitude Sinus Titanum - - - - - - - -	1877	S. 18°.17
" " " - - - - - - - -	1879	S. 19°.33
" " " - - - - - - - -	1894	S. 20°.0

The cause that at once suggests itself for such discrepancy between the calculated and the present observed positions is that the received time of rotation of the planet is a trifle too small, and that the longitudes in consequence are falling slowly behind their predicted times of meridian passage. That there is any error in the computation of the ephemeris is, with so admirable a computer as Marth, practically out of the question. Furthermore a preliminary search just made by him in consequence of these observations of mine reveals none.

It is interesting to note that this increase in the Martian longitudes, like many other astronomical matters, has been observed without being recognized before, and by more than one observer.

At the opposition of 1892 Keeler ("Physical Observations of Mars made at the Allegheny Observatory in 1892," in the *Memoirs of the Royal Astronomical Society*) found, on comparing his drawings meridianed by Marth ephemeris with photographs of a globe made by him from Schiaparelli's chart and set to the longitude and latitude of the time of observation:

"that there was a very satisfactory agreement among themselves in the positions of the markings on the various drawings, but that there was a small and nearly constant difference of longitude between the drawings and the photographs of the globe, the longitude of the central meridian on the latter

exceeding that of the drawings by about seven degrees. I therefore made another set of photographs, with slightly different positions of the globe, according to the following plan: The axis of the globe was set to the proper inclination so that the latitude of the center of the image was that of the center of Mars at the time of observation. The globe was turned on its axis until the image on the ground glass was in the best general agreement with the drawing made at that time, and the image was then photographed as before. The agreement of the drawings and photographs in their main features was then remarkably close.

"I am unable to account for this constant difference of longitude. The most natural explanation is that it is due to constant error in estimating the position of the diameter of a large disk, but, according to other experiments, my personal error of estimated bisection is too small to account for the difference."

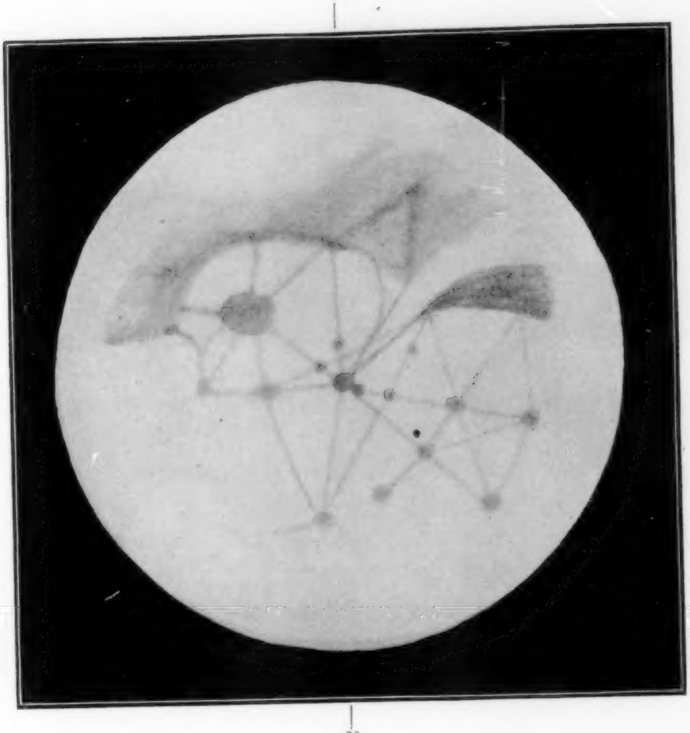
A similar systematic increase in all the longitudes was found in 1890 by Wislicenus at Strasburg, of which in *La Planète Mars* Flammarion simply says: "Ces positions nous paraissent toutes un peu trop à droite."

Both sets of longitudes were a little too much to the right, not because either set of observations was wrong, but because, as I think is now evident, the received time of rotation is too small.

A second point to which I wish to draw attention is the relative desirability of different Martian markings as zero meridians. Of these there are three that commend themselves specially for such purpose, the Fastigium Aryn, the Lacus Phœnicis and the Sinus Titanum. Each of the three possesses certain advantages over the other two, and certain corresponding disadvantages. In the first place all are affected in visibility and, therefore, in effectiveness for the present purpose by the seasonal change that sweeps across the face of the planet. Before the summer solstice of the southern hemisphere, the Sinus Titanum is much more difficult to identify than it afterwards becomes. This is owing to the obliteration early in the season of Atlantis. Before this peninsula has differentiated itself from the Mare Sirenum on the one side and the Mare Cimmerium on the other, the Sinus Titanum is itself inconspicuous, being simply a depression in a more or less straight coast line. After Atlantis has appeared, however, the Sinus Titanum is perhaps the most prominent mark-

PLATE XX

S



N

MARS

Lacus Phœnicis at November Presentation

ing on the disk. For a zero meridian, therefore, it is not good before the summer solstice of its hemisphere and excellent afterward. This was certainly the case this year, and if we may judge generally by this year's changes, which I think we may, should be true at subsequent oppositions.

On the other hand the Lacus Phœnicis proved this year better early in the season than late. At the end of August, that is about the time of the summer solstice of the Southern hemisphere, it was more conspicuous than it turned out to be in November. As the observations taken on it for longitude were made at the latter date, its position is not so satisfactory as that of the Sinus Titanum. Its probable error comes out some five times as great as that of the latter marking.

With the Fastigium Aryn lateness in the season also proved a drawback. Although I got a better result in November than in October, this was due not to the intrinsic ease of the later observations, but to the greater care with which the latter were taken. The fading out of the region of the Sabæus Sinus between its October and November presentations was most marked, and very unpleasantly so.

If the best results, therefore, are to be hoped for, each marking must be observed at the oppositions specially suited to it. For as Mars comes to opposition at changing seasons of its year, and the conspicuousness of any marking is apparently a matter of the seasonal change then in progress upon its hemisphere, different oppositions are favorable to special features.

In the subjoined table the figures in the first column represent the observed longitudes; those in the third the longitudes reckoned from the Fastigium Aryn, the latter being therefore the true Martian longitudes referred to the established zero meridian.

DETERMINATION OF POINTS ON THE SURFACE OF MARS — 1894.

No. of Obs.		Weight			Long.	Lat.	Long.	Lat.
Long.	Lat.	Long.	Lat.					
10	2	3	1	Fastigium Aryn	5°.1	2°.8	0°.	N. 1°.
1	..	1	..	West Sabæus Sinus (bottom of gulf)	10°.4		5°.3	
3	..	2	..	East cape of Margaritifer Sinus	15°.5		10°.4	
1	..	1	..	Margaritifer Sinus (mouth of the Indus)	21°.4		16°.3	
2	..	1	..	Margaritifer Sinus (mouth of the Hydaspes)	25°.5		20°.4	
3	..	2	..	Aromi Promontory	35°.1		30°.0	S. 6°.
3	3	2	1	Auroræ Sinus (center)	54°.1		49°.	S. 11°.
2	..	2	..	West Ganges (mouth of)	59°.7		54°.6	
..	1	..	1	Lacus Lunæ				N. 24°.4
6	4	4	2	Solis Lacus (center)	91°.3		86°.2	S. 28°.2
4	3	2	1	Lacus Phœnicis	112°.8		107°.7	S. 16°.7
3	..	2	..	Mare Sirenum (beak of)	126°.6			
..	2	..	2	Mare Sirenum (middle of N. coast)				S. 29°.9
..	1	..	1	Oasis (junc. Gigas and Pyriphlegethon)				N. 5°.
1	..	1	..	Oasis (junc. Pyriphlegethon and Steropes)	142°.7		137°.6	
1	1	1	1	Oasis (junc. Eumenides and Gigas)	149°.5		144°.4	S. 7°.2
1	..	1	..	Oasis on Orcus	154°.6		149°.5	
2	..	1	..	Oasis (junc. Orcus and Steropes)	159°.2		154°.1	
5	4	5	2	Sinus Titanum	174°.5		169°.4	S. 20°.
1	1	1	1	Scamander	203°.5		198°.4	S. 35°.7
1	..	1	..	Trivium Charontis	208°.5		203°.4	
1	..	1	..	Mare Cimmerium (mouth of the Palinurus)	215°.		209°.9	
1	..	1	..	Mare Cimmerium (mouth of the Avernus)	221°.		215°.9	
1	..	1	..	Mare Cimmerium (mouth of the Æthiops)	243°.		237°.9	
1	1	1	1	Eridania (center)	218°.		212°.9	S. 32°.6
..	1	..	1	North coast of Islands				S. 33°.6
1	..	1	..	Ausonia (center)	248°.4		243°.3	
1	1	1	1	Lybia (southern extremity)	272°.		266°.9	S. 8°.5
1	1	1	1	Circe Promontory	281°.		275°.9	S. 6°.7
2	..	2	..	Syrtis Major (mouth of the Astapus)	292°.4		287°.3	
2	3	2	2	Hellas (center of northern end)	303°.8		298°.7	S. 30°.3
3	7	3	2	Hammonis Cornu	319°.6		314°.5	S. 11°.6
1	..	1	..	Euphrates } mouths	336°.1		331°.	
5	6	3	3	of double	339°.4		334°.3	S. 9°.0
3	..	2	..	Phison } canals	343°.1		338°.	
6	3	3	2	Edom Promontory	357°.6		352°.5	S. 8°.2

LOWELL OBSERVATORY,
February, 1895.

A COMBINATION TELESCOPE AND DOME.

By A. E. Douglass.

By a curious coincidence this form of telescope mounting was completed in its essentials on the day in which the writer first heard of Sir Howard Grubb's "aquatic" mounting for a reflector.[1] The two mountings have features in common, of which the most important is an attempt to procure rigidity of support and steadiness of movement.

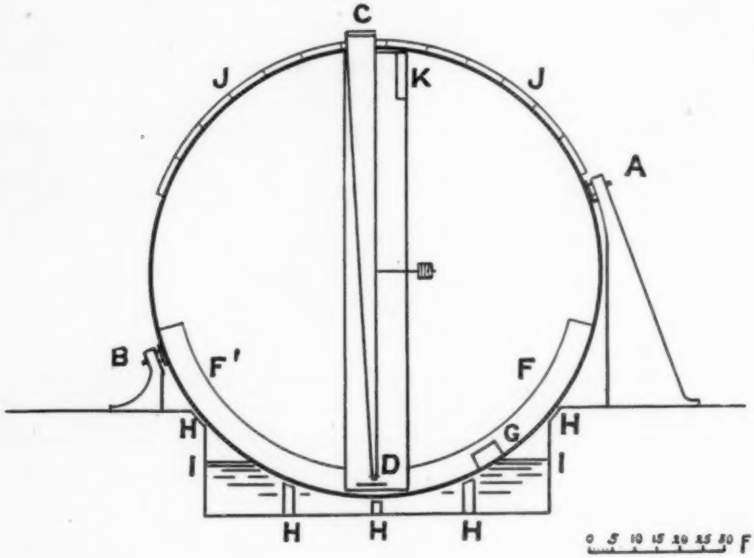
Complaints of unsteadiness while using the micrometer are common against the ordinary form of mounting. This instability is due to irregularities of the clock movement and lack of rigidity in the mounting. A slight wind becomes a most annoying visitor and an accidental touch sets the tube vibrating in a most aggravating manner. The first idea in the development of the spherical telescope (a provisional name adopted here for convenience) was that much movement could be eliminated by applying the motive power near the eye-end of the tube. Still further stability would be insured if the tube were held at each end instead of at the middle. The final step was to place the tube inside a sphere mounted like an ordinary globe. The following pages will present various mechanical difficulties of the plan and suggest solutions. As a matter of convenience the dimensions recommended will be such as might apply to a sphere 100 feet in diameter and a lens of seventy-two inches.

I. SUPPORT AND ADJUSTMENT OF SPHERE.

The sphere floats on water which is confined in a circular cistern of sufficient diameter and depth. At the bottom are several supports upon which it can rest while in process of construction or repair. Its normal position would be less than one foot above these. The sphere itself should be made of thin steel, well braced. It is not necessary that it should have a perfectly

[1] In *New York World* (about) November 11, 1894. For original article see *Knowledge* for May, 1894.

spherical surface, but it can be put together of flat plates. The bearings for the axis consist in anti-friction wheels which are mounted in a single casting capable of vertical motion, between guides, of about one foot. Fine polar adjustment can be effected by some movement within this casting. Each casting is supported on a rod which passes into a cylinder below and is attached to the center of a transverse diaphragm of slightly flexible



EXPLANATION OF FIG. 1.—A and B are the poles of the sphere. C is the objective and D is the eye-end of telescope. F F' is the walk passing beside the zone in which revolves the declination carriage. G is the driving motor and machinery. H, H, etc., are the supports for dome during construction or repair. I and I show the water level for eight-foot draught. J, J are the shutters. K is the tank near objective. The entrance will be near F'.

material dividing it into two parts.[2] The cylinders are filled with water and the upper part of one is joined to the lower part of the other, so that by a transmission of pressure from one diaphragm to the other any variation in one pole causes an equal variation

[2] The idea of using a diaphragm instead of an ordinary piston is due to Mr. G. Sykes of this town. I have also to thank him for other important suggestions and for much assistance with mechanical problems.

in the other. By this arrangement also the sphere sinks deeper into the water with added weight, or rises with lessened weight, and pressure on the bearings is only momentary. For high latitudes the plan should be somewhat modified, but I am inclined to think that large telescopes of the future, if properly located, will be between 15° and 25° from the equator.

A brief computation shows that a spherical shell of half-inch steel (which I am told is a reasonable allowance for bracing), 100 feet in diameter, must weigh approximately 300 tons, and when floating on water have a draught of eight feet. The addition of 300 pounds (one person's weight doubled by the balancing system adopted) would cause it to sink $\frac{1}{40}$ inch deeper in the water. If the diameter of the cistern is seventy feet and the water is allowed to crowd up around the dome its theoretical sinkage will be only $\frac{1}{260}$ inch.

II. RIGHT ASCENSION MOVEMENT.

a. Driving mechanism; slow motions.

The driving-gear is located within the dome at its equator, nearly opposite the opening for the lens. Fig. 2 gives a scheme for the driving apparatus, in which B is an electric motor whose rate of revolution is controlled by a tuning-fork (see F. L. O. Wadsworth in THE ASTROPHYSICAL JOURNAL, February 1895, pages 176–7). A is a sprocket wheel which is, in connection with an ordinary weight driving-gear, to be used when the electric power fails. This wheel is ordinarily loose on its axle, but can be connected at will. Wheels C and E carry the power to G, where it passes a "mouse control" of the Greenwich pattern. From M the motion passes through P and Q and the beveled wheels R and S. The last mentioned, being the last wheel inside the dome, should have an index connected with it which will easily give the hour angle within one second of time. The axle of S passes through the floor of the dome to the wheel T outside, which, engaging with a circular rack, whose radius is slightly greater than that of the dome, causes the entire sphere to revolve. As the dome is made to sink deeper in the water with

increase of weight, the rack must descend with it. The required motion can be imparted by using as support to the rack suitable bearings placed upon the surface of the sphere, while the rack itself is prevented from revolving by stops which slide against fixed brackets in the tank.

b. Rapid motion in right ascension.

This is obtained by moving C and D bodily towards the

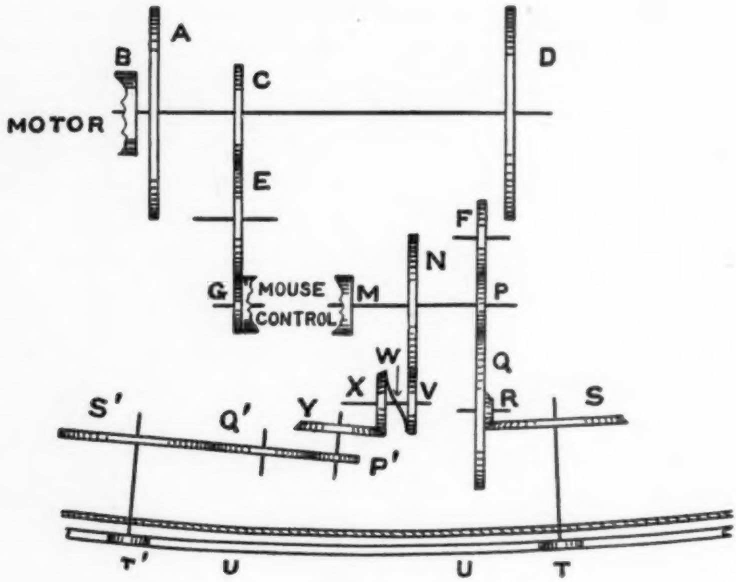


Fig. 2

motor so that C is wholly disengaged from E, and D transmits the power to P through F. By this means and by an arrangement of brushes the mouse control and the tuning-fork are cut out during rapid motion.

c. Backlash absorber.

T′, S′, R′, Q′, P′, Y, and X are so geared with respect to T, S, R, Q, P, N, and V, that V and X revolve at the same rate and in the same direction. If, therefore, by means of a spring, W, we produce in V and X a tendency to turn in opposite direc-

tions, the teeth of T and T′ will oppose each other by a force depending on the strength of W. This will produce an increase of friction between T and U, but the amount can be regulated by the tension of W. By means of this spring, however, both backlash and accidental slipping of T in U may be avoided. The displacement of a star in the focus is twice the amount of such slipping.

d. Automatic balance.

A tank of thirty to sixty cubic feet capacity is placed near the objective and moves with it. When the sphere is thrown out of balance a change occurs in the otherwise constant strain upon each wheel of the driving-gear. The wheel M (Fig. 2) is therefore made in two parts, held in a normal position by a spring, but capable of a slight motion with reference to each other in either direction. Electrodes are so placed that different circuits are closed according to the direction of motion of these parts, and an arrangement is connected with the right ascension index so that on the meridian these circuits are reversed. One circuit, by opening valves, admits water into the tank and the other allows water to escape. In this manner and by a proper arrangement of wires balancing can be effected automatically. To avoid possible disturbance during delicate work a switch at the observing chair can clamp the two parts of M together.

III. DECLINATION MOVEMENT.

The sphere has a long opening in it extending from the upper pole along a meridian to within a reasonable distance of the opposite horizon. The great circle including this opening is the declination circle. The declination axis, in the center of this circle and perpendicular to it, is stationary in the sphere. The tube passes up to one side of the axis and is supported in a special framework which rotates about the axis, the other side of the framework, or carriage, being extended for balancing purposes; a ladder runs from top to bottom. A strong clamp is desirable at each side of the top and bottom to keep the carriage perfectly steady and aid in rigidity of the dome. By taking the

best advantage of every opportunity of bracing there seems to be no doubt that the two halves can be made sufficiently rigid with respect to each other. At the top of the declination carriage is the tank previously mentioned. Its best form is tubular and it should be placed parallel to the telescope. By making the objective project ten or twenty feet and surrounding the upper part of the tube by an air space connecting with the interior, the size of the sphere may perhaps be appreciably reduced. The declination carriage will be rotated by a crank and cog-wheel near the observing chair. An index can be placed on the carriage moving along a stationary scale of which each degree will be about one foot; setting within a small part of a degree will be easy.

IV. SUSPENSION OF THE TELESCOPE TUBE.

The lens is supported in a massive compass-mounting which will allow the eye-end of the tube to occupy any part of a circle whose diameter is about 1°. The chief function of the tube will be to preserve the alignment between the objective and eyepiece, and it may be made as light as will be consistent with rigidity. The position of the eye-end will be controlled by two large micrometer screws, whose revolutions may be read off from a scale, thus giving us a micrometer of unusually extensive field. This plan, or some modification allowing rotation, admits the use of high-power negative eyepieces for measuring purposes. A small position micrometer should be attached to the draw-tube.

Finder.

The finder need not be very large, but should be mounted so that its focus would be decidedly below that of the great telescope. Then by means of two mirrors its optical axis could be brought near and parallel to that of the other instrument and its focus rendered equally accessible to the observer. A rotating disk near its focus would carry eyepieces of different power. When an object had been found with a low power and large field and brought to the intersection of cross-threads, a high power could be turned in at once which would insure its visibility in the

large instrument. A rotary movement in either one of the elbows will throw the eye-end of the finder out of the way when the object is finally in position.

V. SHUTTERS AND CAP.

The long portions of the opening which are not covered by the top of the declination carriage are closed by automatic shutters which open on the approach of the lens and close on its retreat. This is effected by a system of cog-wheels and eccentrics. It will probably be found best to extend the top of the carriage in either direction by a light screen to prevent too free entrance of outside air. The entrance of cold night air might be regulated by ventilators capable of adjustment.

The cap for the lens consists of two halves which separate in opposite directions to balance each other, controlled by a windlass near the observing chair.

VI. OBSERVING CHAIR AND ACCESSORIES.

An iron post projects from the floor of the declination carriage in line with the optical axis of the telescope in its central position. About this as an axis a car revolves on a circular track, supporting the observing chair proper on radial tracks. The chair may be constructed to suit individual taste; the following plan will serve as an example. Near the center of the chair-base two boards are hinged, one supporting the back and head, and the other the knees and feet. The latter has a second hinge at the knees, so that by drawing the footboard from its outermost position towards the center a seat is formed (for observations at low altitudes). The headboard should be kept raised a little and made adjustable through a small arc, and the whole cushioned. At the top of the headboard is a transverse strip of wood which can be raised or lowered through the space of two inches by a lever which passes down beside the headboard to be within reach of the hand. Upon this strip a small head-rest is placed having a lateral sliding motion. On either end of the rest is a mirror placed at an angle of 45°, by means of which the micrometer readings may be taken; otherwise the eye can

scarcely get far enough away to see the scale. Eyepieces should be kept in a drawer in one side of the chair so that they can be reached without getting up. A switchboard containing all necessary electric connections can be suspended by the slack of its wires from some point above so that it can be hooked on to the observing chair within reach.

Time.

Time had best be brought in to a sounder from a standard clock in an adjoining building. This may be used to correct a watch mounted, I would suggest, on the telescope itself, facing the observer, so that the time may be noted as soon as an observation is complete.

Recording.

It might be possible to attach to the telescope or head-rest two mirrors which would bring the record-book into view with one eye while the other was occupied at the eyepiece. This would be especially serviceable in making drawings of planetary detail.

VII. ENTRANCE.

The outside door is in the declination circle, and as far as possible below the lower pole without interfering with the motion of the carriage. The door itself is arranged to rotate about its center so that in any position of the dome it can be turned upright. It is reached by a U-shaped stairway. Inside, from the level of the door throughout the whole range of movement of the lower end of the carriage, a pathway, a quadrant in section, is built on each side of the declination zone. The two pathways if placed together would make a semicircle with its center tangent to the inner surface of the sphere. When the hour angle is zero a person may step from the carriage to the pathway on either side, the nearest part of it being then level; for eastern hour angles, he can find on the eastern pathway a part where the east and west inclination will be very small; for western hour angles he will turn to the western pathway. The radius of curvature of the section of these pathways could be perhaps five

feet, and the ways themselves could be divided into separate paths by raised strips so as to make it easier to walk on them. Each of these separate paths will be supplied with steps of the proper height or with cleats nailed across, as best suits the inclination at which it will be used. At the equator a side path will extend at right angles to give access to the motors, driving-gear and desk. One-half of this path will have cleats across for small inclinations of the dome and the other half will be a stairway which can be used for large inclination in either direction. The desk will be of a form suited to the necessities of the case. The stand in front of it and its own top will both be curved surfaces so that one may always find a level standing place and a level part of the desk to write upon. These two surfaces will be portions of concentric cylinders whose axis is parallel to the axis of the dome.

A second entrance is placed near the objective, with a ladder bolted to the outside of the sphere for approaching it.

VIII. COMPARISON WITH OTHER MOUNTINGS.

The forms of equatorial mountings now in use differ as to their stability; perhaps the best in this respect is the *Equatorial Coudé*. By shortening the equatorial arm increased firmness will result, but it always has a disadvantage in requiring two mirrors. Irregularities in clock motion may occur in the *Coudé* as well as in any other form, whereas with a spherical telescope, the power being applied at the greatest possible distance from the axis, imperfections in the clock appear unchanged instead of highly magnified. Its great inertia also will aid in giving a constant motion. Apparently the individual feature in this mounting which cannot be duplicated in any other is the application of clock-power so far from the axis, resulting in great strength and steadiness.

In this connection it will be interesting to note what power is now in use in telescopes of some size—remembering that the single right ascension movement of the design under consideration includes both right ascension movement and turning of

domes in the ordinary mounting. Through the courtesy of the Director and Secretary of the Lick Observatory, and of Messrs. Warner & Swasey, I have received data on this subject which I can here present:

RIGHT ASCENSION MOVEMENT.

Telescope	Size in.	Weight moved tons	Slow motion H.P.	Quick motion H.P.	Time 1 Rot. m.	Work ft. lbs.	Maker
Lowell...	18	about 1	0.0003	0.0455	0.5	750	Clark
Naval Ob.	26	—	0.0020	—	—	—	Warner & Swasey
Lick	36	14.2	0.0033	0.0295	3.2	3,110	"
Yerkes...	40	—	0.0107	0.1175	4.0	15,510	"

POWER REQUIRED FOR TURNING DOMES.

Dome	Diam. ft.	Weight tons	Power	Time 1 Rot. m.	Work ft. lbs.	Designer
Lowell[1]...	35	3	0.22	2.0	14,400	W. H. Pickering
Naval Ob..	45	—	0.07	2.5	5,773	Warner & Swasey
Lick	75	100	1.18	8.0	312,000	Union Iron Works, San Francisco
Yerkes....	90	165	—	—	—	Warner & Swasey

From an examination of the above figures it seems probable that one horse-power is not an over-estimate for a telescope of seventy-two inches aperture. If we could entirely disregard friction this would undoubtedly be far more than sufficient; but in a new machine friction is a very uncertain factor as well as a most important one, and actual experiments are the only reliable source of information. The only satisfactory form that such experiments could take would be to try the dome on a small scale, as, for instance, arranged for an eighteen-inch telescope. A study of the different sources of friction leads me to think that the mechanical power required will be small.

LOWELL OBSERVATORY,
March 7, 1895.

[1] The design of this dome closely follows that suggested in *A. and A.*, January, 1894. The work of turning it could be enormously reduced by substituting iron for wooden tracks and stiffening the live-ring horizontally.

STARS HAVING PECULIAR SPECTRA.[1]

ELEVEN NEW VARIABLE STARS.

By M. Fleming.

An examination of the photographs of stellar spectra taken at Arequipa, Peru, under the direction of Professor S. I. Bailey, and forming part of the work of the Henry Draper Memorial, has, during the last few months, shown marked peculiarities in the spectra of eleven objects enumerated in Table I, and has resulted in the discovery of eleven new variable stars enumerated in Table II. The first column of Table I gives the designation of the object and is followed by the approximate right ascension and declination for 1900, the catalogue magnitude, and a brief description of the photographic spectrum:

TABLE I.

Designation	R.A. 1900	Dec. 1900	Mag.	Description
Z.C. 3^h 1404	3^h $46^m.7$	$-43°$ $50'$	8.5	Type IV
S.B.D.$-22°$ 1070	5 14 .5	-22 19	8.7	Peculiar
N.G.C. 2070	5 40 .5	-69 43	..	Bright lines, Gas. Neb.
A.G.C. 8518	6 46 .1	-32 24	4.0	$H\beta$ bright
A.G.C. 9181	7 10 .2	-26 10	5.4	$H\beta$ bright
....	7 19 .5	$+9$ 7	..	Bright lines, Gas. Neb.
Cord. D.$-31°$ 5004	7 41 .1	-31 41	9.2	Type V
Z.C. 7^h 2999	7 42 .0	-34 8	9.5	Bright lines, Gas. Neb.
....	16 16 .8	-51 18	..	Type V
....	16 39 .8	-67 36	..	Type IV
Z.C. 17^h 734	17 13 .2	-66 15	8.5	Peculiar

The gaseous nebula whose approximate position for 1900 is in R.A. 7^h $19^m.5$, Dec. $+9°$ $7'$ was found in the examination of the photographs taken with the 8-inch Draper telescope at Cambridge.

[1] Communicated by Edward C. Pickering, Director of the Harvard College Observatory.

The stars contained in Table II have a spectrum of the third type, having also the hydrogen lines bright, and their variability was at once suspected from this peculiarity. Conclusive evidence of their variation, as shown below, was in each case obtained on examination of chart plates of these regions. They are not here announced as suspected variables, but as variable stars, the variation, in each case, having been confirmed independently from an examination of the photographs by Professor Edward C. Pickering. The first column gives the constellation, and the second, the catalogue designation. This is followed by the approximate right ascension and declination for 1900, the number of photographs examined, and the maximum and minimum photographic magnitude as derived from the photographs:

TABLE II.

Constell.	Designation	R.A. 1900	Dec. 1900	No. Plates	Mag.	
					Max.	Min.
Tucana	....	0^h $18^m.4$	$-62°$ $14'$	15	8.7	<11.6
Pictor	*A.G.C.* 5428	4 43 .5	-49 25	16	8.1	9.5
Lepus	*S.B.D.*—22° 995	5 0 .6	-22 2	13	8.2	10.9
Pictor	*Z.C.* 5^h 283	5 8 .3	-48 38	16	8.6	<13.3
Scorpius	....	17 35 .1	-43 42	37	9.3	12.7
Telescopium	....	20 7 .6	-47 18	7	8.4	11.6
Indus	*Z.C.* 20^h 1539	20 49 .0	-54 42	26	8.4	<12.4
Octans	....	20 57 .4	-82 30	28	9.0	<12.5
Grus	....	21 42 .1	-47 22	25	8.4	<12.5
Aquarius	....	22 13 .2	-21 26	18	8.4	11.6
Phœnix	*A.G.C.* 32334	23 53 .9	-57 8	22	7.2	8.7

—Tucanae, R.A. 0^h $18^m.4$, Dec. $-62°$ $14'$. The magnitudes of this star as derived from photographs taken on September 11, October 8, November 28, 1889; September 12, September 23, 1890; August 20, September 17, October 4, October 4, October 26, 1891; July 31, September 5, 1892; October 23, 1893; July 6, and July 23, 1894, are <10.9, 10.6, 9.4; 9.4, 9.7; <10.7, <11.3, <11.5, <11.6, 11.3; 8.7, 9.2; <10.3; 8.8 and 9.0 respectively.

—Pictoris, *A.G.C.* 5428. The magnitudes of this star as

derived from photographs taken on September 26, September 26, October 4, October 8, 1889; September 23, 1890; October 26, 1891; September 28, September 29, December 8, 1892; November 18, 1893; August 21, August 25, September 14, September 19, September 19, and October 19, 1894, are 8.5, 8.3, 8.5, 8.6; 8.8; 8.6; 8.6, 8.6, 9.5; 9.0; 8.1, 8.2, 8.4, 8.5, 8.5, and 8.9 respectively.

— Leporis, *S.B.D.* — 22°995. The magnitudes of this star as derived from photographs taken on November 4, November 17, 1889; February 3, September 19, September 19, December 29, 1890; January 26, 1891; November 18, 1893; September 14, October 24, 1894; March 5, March 9, and March 16, 1895, are 9.2, 8.4; 9.4, 10.5, 10.3, 8.4; 9.4; 8.2; 10.4, 9.0; 10.9, 10.8, and 10.8 respectively.

— Pictoris, *Z.C.* 5^h 283. The magnitudes of this star as derived from photographs taken on September 26, September 26, October 8, November 6, 1889; September 23, 1890; October 24, November 23, 1891; September 28, October 6, December 8, 1892; September 27, September 27, November 18, 1893; September 14, September 19, and November 5, 1894, are <10.8, <11.1, <11.8, <12.7; <13.2; <13.3, <11.4; 11.5, 12.0, <13.3; 10.6, 10.6, 11.4; 11.3, 11.0, and 8.6 respectively.

— Scorpii. R.A. $17^h\ 35^m.1$, Dec. $-43°\ 42'$. The magnitudes of this star as derived from photographs taken on July 9, July 9, July 13, July 17, July 19, July 20, July 21, July 22, August 6, August 28, 1889; May 9, June 9, June 9, 1890; May 18, May 18, May 19, May 19, September 8, 1891; April 19, June 6, June 10, 1892; April 27, May 1, May 1, May 8, May 8, June 24, 1893; May 23, June 1, June 1, June 1, June 1, June 14, July 20, July 20, August 14 and September 21, 1894, are 9.9, 9.8, 9.8, 9.6, 9.8, 9.6, 9.5, 9.5, 9.3, 9.6; 11.4, 10.7, 10.8; <11.8, <10.7, 12.4, <12.2, 9.6; <11.1, 10.8, 10.8; <11.1, 12.6, <11.6, 12.7, <12.4, 11.5; <12.3, <12.1, <11.8, <11.6, <11.3, <12.3, 11.4, 11.2, 10.7 and 9.9 respectively.

— Telescopii. R.A. $20^h\ 7^m.6$, Dec. $-47°\ 18'$. The magnitudes of this star as derived from photographs taken on July 24, 1893;

July 21, August 21, September 12, September 15, September 15 and September 27, 1894, are 8.7; 11.6, 11.6, 9.0, 9.1, 8.9 and 8.4 respectively.

—Indi. *Z.C.* 20^h 1539. The magnitudes of this star as derived from photographs taken on June 20, July 5, July 19, July 21, July 22, August 22, October 26, 1889; May 21, May 22, June 2, June 10, June 10, July 16, 1891; September 8, September 8, September 8, 1892; June 27, July 31, July 31, September 23, September 23, 1893; May 21, July 13, July 25, August 11 and August 11, 1894, are 10.3?, <11.3, <12.3, <11.9, <11.6, <12.4, <9.9; 11.3, 11.7, <12.1, <10.4, 12.0, <10.2; <11.1, <12.2, <12.2; 10.2, 11.3, 11.4, <12.2, <12.3; 8.4, 9.3, 9.7, 10.1 and 10.1 respectively.

—Octantis. R.A. $20^h\ 57^m.4$, Dec. $-82°\ 30'$. The magnitudes of this star as derived from photographs taken on June 17, June 18, June 20, August 8, September 4, September 16, September 27, October 1, 1889; June 9, June 13, June 14, August 5, September 5, 1890; June 11, June 11, June 11, June 14, June 19, October 19, October 19, 1891; May 3, June 23, 1893; July 16, July 16, August 2, August 13, August 14 and September 10, 1894, are 12.4, 11.8, <11.7, <10.8, <10.4, <10.3, <12.3, <11.8; 9.8, 9.5, 9.5, 10.3, 12.0; <11.2, <10.4, <12.5, <10.9, <12.5, 10.6, 10.6; <12.5, 9.8; 11.3, 11.2, 9.0, 9.1, 9.0 and 9.1 respectively.

—Gruis. R.A. $21^h\ 42^m.1$, Dec. $-47°\ 22'$. The magnitudes of this star as derived from photographs taken on June 20, June 20, July 13, July 13, July 13, July 18, July 18, July 22, September 11, September 28, October 8, 1889; June 12, 1890; May 20, June 8, June 8, June 8, June 13, July 16, 1891; October 6, October 6, 1892; July 24, July 24, August 21, August 21, 1893; May 21 and August 31, 1894, are <10.5, <10.5, <11.1, <11.5, <11.7, <12.4, <12.5, <12.3; <11.6, <10.5, <11.7; 11.9; <11.8, <10.5, <11.8, <10.1, <10.8, <12.2; 8.8, 8.8; 11.8, 11.7, 10.2, 10.6; <11.6 and 8.4 respectively. The magnitude 10.2 on August 21, 1893, may be somewhat in error since the image of the variable is near the edge of the plate, thus rendering the comparison difficult.

–Aquarii. R.A. $22^h\ 13^m.2$, Dec. $-21°\ 26'$. The magnitudes of this star as derived from photographs taken on August 28, September 3, September 25, September 27, September 30, September 30, October 24, 1889; July 7, July 10, 1890; June 14, June 16, 1891; July 3, 1892; September 20, September 20, October 25, October 25, 1893; August 10 and August 11, 1894, are 10.0, 10.0, $<$10.6, 10.6, 10.8, 10.8, 11.6; 10.0, 9.9; 10.9, $<$10.6; $<$10.4; 9.4, 9.4, 9.3, 9.3; 8.5 and 8.4 respectively.

–Phoenicis. *A.G.C.* 32334. The magnitudes of this star as derived from photographs taken on July 17, August 20, September 11, October 8, October 8, 1889; June 30, August 20, August 20, August 21, September 17, 1891; May 16, May 16, August 16, September 5, 1892; July 24, July 27, August 21, September 20, September 27, October 23, November 17, 1893; and July 24, 1894, are 8.2, 8.4, 8.4, 7.2, 7.5; 8.7, 7.8, 7.7, 8.2, 8.3; 8.2, 8.2, 8.4, 8.4; 8.4, 8.2, 8.2, 8.1, 8.3, 8.2, 8.6; and 8.0 respectively.

The magnitudes given above for the new variable star in Aquarius were derived from the mean of two or more measures made independently on two different dates, and using a different set of comparison stars when the variable was faint. The average difference of these measures is $\pm$ .09.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., April 9, 1895.

A SPECTROSCOPIC PROOF OF THE METEORIC CONSTITUTION OF SATURN'S RINGS.

By James E. Keeler.

The hypothesis that the rings of Saturn are composed of an immense multitude of comparatively small bodies, revolving around Saturn in circular orbits, has been firmly established since the publication of Maxwell's classical paper in 1859. The grounds on which the hypothesis is based are too well known to require special mention. All the observed phenomena of the rings are naturally and completely explained by it, and mathematical investigation shows that a solid or fluid ring could not exist under the circumstances in which the actual ring is placed.

I have recently obtained a spectroscopic proof of the meteoric constitution of the ring, which is of interest because it is the first *direct* proof of the correctness of the accepted hypothesis, and because it illustrates in a very beautiful manner (as I think) the fruitfulness of Doppler's principle, and the value of the spectroscope as an instrument for the measurement of celestial motions.

Since the relative velocities of different parts of the ring would be essentially different under the two hypotheses of rigid structure and meteoric constitution, it is possible to distinguish between these hypotheses by measuring the motion of different parts of the ring in the line of sight. The only difficulty is to find a method so delicate that the very small differences of velocity in question may not be masked by instrumental errors. Success in visual observations of the spectrum is hardly to be expected.

Soon after the large spectroscope of the Allegheny Observatory was completed, in 1893, I attempted to determine the relative motions of different parts of the system of Saturn, by photographing the spectrum with the slit parallel to the major axis of

the ring, but failed to obtain satisfactory results. The unfavorable atmospheric conditions at Allegheny, the strong yellow color of the objective of the thirteen-inch equatorial, and the yellow color of Saturn itself so reduced the intensity of the violet part of the spectrum that the negatives obtained with a sufficiently high dispersion were too weak and granular to admit of measurement. Another unfavorable circumstance was the fact that I had to guide the practically invisible image corresponding to the $H\gamma$ line by means of the visual image, which was greatly out of focus on account of the chromatic aberration of the visually corrected telescope. Having recently obtained excellent results in other directions with orthochromatic plates, by the use of which the difficulties mentioned above are to a great extent obviated, I was induced to repeat my earlier attempts, and obtained two fine photographs of the lower spectrum of Saturn on April 9 and 10 of the present year. The exposure in each case was two hours, and the image of the planet was kept very accurately central on the slit-plate. After the exposure the spectrum of the Moon was photographed on each side of the spectrum of Saturn, and nearly in contact with it. Each part of the lunar spectrum has a width of about one millimeter, which is also nearly the extreme width of the planetary spectrum. On both sides of the spectrum of the ball of the planet are the narrow spectra of the ansæ of the ring.

The length of the spectrum from *b* to D is 23 millimeters. The focus was adjusted on the line $\lambda 5352$, a little above the position of maximum sensitiveness of an orthochromatic plate, in the yellow green. On both plates the densities of the different spectra are very nearly equal, and the definition is excellent. It is hardly necessary to say that all the lenses used in the apparatus are visually corrected objectives.

These photographs not only show very clearly the relative displacement of the lines in the spectrum of the ring, due to the opposite motions of the ansæ, but exhibit another peculiarity, which is of special importance in connection with the subject of the present paper. The planetary lines are strongly inclined, in

consequence of the rotation of the ball, but the lines in the spectra of the ansæ do not follow the direction of the lines in the central spectrum; they are nearly parallel to the lines of the comparison spectrum, and, in fact, as compared with the lines of the ball, have a slight tendency to incline in the opposite direction. Hence the outer ends of these lines are less displaced than the inner ends. Now it is evident that if the ring rotated as a whole the velocity of the outer edge would exceed that of the inner edge, and the lines of the ansæ would be inclined in the same direction as those of the ball of the planet. If, on the other hand, the ring is an aggregation of satellites revolving around Saturn, the velocity would be greatest at the inner edge, and the inclination of lines in the spectra of the ansæ would be reversed. The photographs are therefore a direct proof of the approximate correctness of the latter supposition.

To apply more precise reasoning to the subject under consideration, let us determine the form of a line in the spectrum of Saturn when the slit is in the major axis of the ring, on the assumption that the planet rotates as a solid body and the ring is a swarm of particles revolving in circular orbits according to Kepler's third law. At present the motion of the system as a whole is neglected. The upper part of Fig. 1 represents the image of Saturn on the slit of the spectroscope (the scale above it applies to the instrument used at Allegheny), and the narrow horizontal line in the lower part of the figure represents an undisplaced line in the spectrum, or solar line.[1] Let this line be taken as the axis of x, and the perpendicular line through its center as the axis of y. The red end of the spectrum is supposed to be in the direction of the positive axis of y, and the camera and collimator of the spectroscope are assumed to have the same focal length, so that the breadth of the spectrum is equal to the length of the illuminated part of the slit. Corresponding points in the slit and spectral line will then have the same value of x.

Now let x, y, be the coördinates of a point on the displaced line,

[1] The curvature of the line in a prismatic spectrum need not be considered.

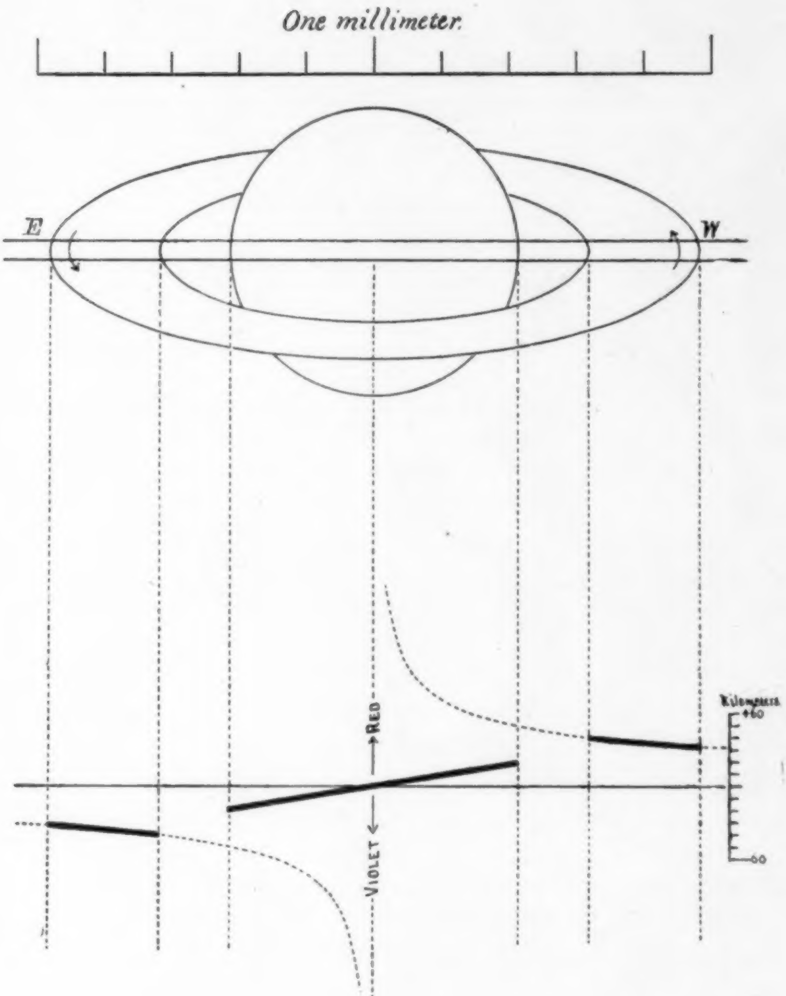


FIG. 1

v = velocity of point corresponding to x, y in the line of sight,

V' = velocity of a point on the equator of Saturn,

α = angle between the line of sight and the radius of Saturn which passes through the point corresponding to x, y,

2ρ = width of spectrum,

β = elevation of Earth (and Sun) above the plane of the ring.[1]

The displacement y is proportional to the velocity in the line of sight. Then we have

$$x = \rho \sin \alpha,$$

$$y = av = aV' \sin \alpha \cos \beta,$$

$$\frac{y}{x} = \frac{aV'}{\rho} \cos \beta = \text{constant}.$$

Hence the planetary line is straight, but inclined to the solar line at an angle

$$\phi = \tan^{-1} \frac{aV'}{\rho} \cos \beta.$$

To determine the form of a line in the spectrum of the ring, regarded as a collection of satellites, we have, by Kepler's third law,

$$T^2 = cR^3,$$

or, since $TV = 2\pi R$,

$$V^2 = \frac{4\pi^2}{cR}.$$

Since x is proportional to R and y to v (where v = velocity in the line of sight = $V \cos \beta$), we may write

$$xy^2 = b,$$

which is the equation to the curve of which the lines in the spectrum of the ring are a part. The curve is represented by the dotted line in the figure; it is symmetrical with respect to the axis of x, but only the upper branch has a physical meaning, and the curve corresponding to the other half of the image is obtained by taking both x and y with negative values.

In the equation $V = \frac{k}{\sqrt{R}}$, $\log k = 3.7992$ for the Saturnian system, R being expressed in kilometers and V in kilometers per

[1] The slight error introduced by the assumption that the Earth and Sun are in the same direction from Saturn is inappreciable, when Saturn is anywhere near opposition.

second. The computed motions of different parts of the system are given in the following table. The gauze ring is not considered, as its spectrum does not appear on the photographs; the rings *A* and *B* are not separately distinguishable.

Object	*R*	Period of a Satellite at Distance *R*	Velocity	Velocity in Line of Sight April 10, 1895
	Kilometers	Hours	Kilometers	Kilometers
Outer edge of ring - -	135,100	13.77	17.14	16.35
Middle of ring - -	112,500	10.46	18.78	17.91
Inner edge of ring - -	89,870	7.47	21.01	20.04
Limb of planet - -	60,340	4.11	25.64	24.46
		Rotation		
Limb of planet - - -	60,340	$10^h.23$(A. Hall)	10.29	9.82

With the values given in the above table, and others which do not correspond to actual points in the system, the dotted curves were platted. For the ordinates, however, twice the values in the last column were taken, since the displacement of a line, due to motion in the line of sight, is doubled in a case of a body which shines by reflected and not by inherent light, provided (as in this case) the Sun and the Earth are in sensibly the same direction from the body. The planetary line is drawn to the same scale, and the heavy lines in the figure represent accurately the aspect of a line in the spectrum of Saturn, with the slit in the axis of the ring, as photographed with a spectroscope having about three times the dispersion of my own instrument. The width of slit which I used ($0^{mm}.028$, or 7900^{km} on the surface of Saturn) is also represented in the figure.

If the whole system has a motion in the line of sight, the lines in the figure will be displaced toward the top or the bottom, as the case may be, but their relative positions will not be altered.

It is evident that in making a photograph of this kind the image must be kept very accurately in the same position on the slit plate, as otherwise the form of the lines shown in the figure would be lost by the superposition of points having different velocities. The second plate was made with special care, and as the air was steadier than on the first occasion, the definition is on

the whole somewhat better than that of plate 1, although the difference is not great. On both plates the aspect of the spectrum is closely in accordance with that indicated by theory and represented in the figure. The planetary lines are inclined from 3° to 4°, and the lines in the spectra of the ansæ have the appearance already described. The slight curvature of the latter indicated by theory is, of course, unrecognizable. On account of the extreme narrowness of the spectra (barely more than a tenth of a millimeter) it was useless to attempt anything like a measurement of the inclination of the lines. The direction of such short lines is frequently masked by irregularities in the grain of the plate, and occasionally a line is considerably distorted. However, in fifty of the sharpest lines, in the region of best definition, only five were inclined in the same direction as the lines of the ball, while the rest were inclined as required by the theory, or elsewhere apparently parallel to the undisplaced lines of the lunar spectrum.

If the ring revolved as a whole, the displacement of lines in its spectrum would follow the same law as for a rotating sphere; that is, the lines would be straight and inclined, their direction passing through the origin. If the ring rotated in the period of its mean radius, a glance at the figure shows that the lines would practically be continuations of the planetary lines. Such an aspect of the lines as this would be recognizable on my photographs at a glance.

It will be seen from the foregoing considerations that the photographs prove not only that the velocity of the inner edge of Saturn's ring exceeds the velocity of the outer edge, but that, within the limits of error of the method, the relative velocities at different parts are such as to satisfy Kepler's third law.

Besides (1) the proof of the meteoric constitution of the rings, explained above, each line of the photographs gives (2) the period of rotation of the planet, (3) the mean period of the rings, (4) the motion of the whole system in the line of sight. I have measured a number of lines on each plate and compared the results with the computed values of the corresponding quantities.

The most accurate method[1] of measuring the relative displacement of the opposite ends of a line in the spectrum of the planet is to measure the angle ϕ.

The value of ϕ depends upon the dispersion and other constants of the spectroscope employed, as well as upon quantities which are independent of the instrument. If we let $L =$ the velocity of light in kilometers per second = 299,860; $\lambda =$ the wave-length of the measured line in tenth-meters; $D =$ the linear dispersion of the photographed spectrum at the position of the same line, expressed in tenth-meters per millimeter; $\rho =$ half the width of the spectrum in millimeters;—we have by Doppler's principle, allowing for the double effect already mentioned,

$$y = x \tan \phi = \frac{2v\lambda}{DL},$$

or,

$$v = x \tan \phi \, D \frac{L}{2\lambda},$$

from which we obtain the velocity in the line of sight at the limb ($V' \cos \beta$) by placing $x = \rho$. That is,

$$V' = \frac{\rho DL \tan \phi}{2\lambda \cos \beta}.$$

The value of ρ is computed from the angular semi-diameter of the planet and the focal length of the telescope. It cannot be obtained accurately by measurement of the photograph, because the borders of the spectrum are indistinct. For my instrument at the time of observation, $\rho = 0^{mm}.2134$. D is obtained from a wave-length curve constructed from measurements of a standard plate of the solar spectrum made with the same apparatus, and ϕ is directly measured under a microscope provided with a position circle.

The relative displacement of a line in the spectra of the ansæ is measured directly, the micrometer wire having first been

[1] This method is due to Deslandres (*C. R.* **120**, 417), and I have found it to be very satisfactory. The conclusions in Deslandres' article, with respect to the motion in the line of sight of bodies which are not self-luminous, are not new, although they are treated more fully than elsewhere.

placed parallel to the lines of the comparison spectrum. If δ is this measured interval, the mean velocity of the ring is

$$V'' = \frac{DL\delta}{4\lambda \cos \beta}.$$

The displacement could also be determined by measuring the angle which the line joining the centers of the two short lines of the ansæ makes with the comparison lines. I have found the direct method to be preferable.

There remains the motion of the whole system in the line of sight, which has hitherto not been considered. It is best determined by comparing the mean of the positions of the lines in the spectra of the ansæ with the corresponding line of the comparison spectrum. The results for this motion are unsatisfactory, as might be expected from the circumstances of observation. Owing to the fall of temperature during the rather long exposure of two hours, and the fact that the lunar spectrum was photographed at the end, and not in the middle of the exposure to the planet, the two spectra are relatively displaced by an amount which is about ten kilometers greater than that due to the motion of Saturn in the line of sight. I have therefore made no careful measurements of this displacement. For the reasons given above, the planetary lines are somewhat less sharp than the lines in the lunar spectrum, which was photographed with an exposure of only six minutes.

The results of all the measurements are given in the following tables:

Photograph No. 1, April 9, 1895.

λ	D	ϕ	Velocity of Limb	$C-O$	δ	Mean Velocity of Ring	$C-O$
Tenth-meters	Tenth-meters	° ′	Kilometers	Kilometers	Millimeters	Kilometers	Kilo-meters
5324.3	27.55	3 36	10.92	−0.63	0.0456	18.54	+0.24
5328.4	27.65	4 24	13.39	−3.10	0.0464	18.92	−0.14
5371.6	28.77	3 11	9.99	+0.30	0.0404	17.01	+1.77
5383.5	29.09	3 20	10.56	−0.27	0.0362	15.37	+3.41
5429.9	30.37	3 8	10.27	+0.02	0.0402	17.67	+1.11
			11.03	−0.74		17.50	+1.28

PHOTOGRAPH No. 2, APRIL 10, 1895.

λ	*D*	φ	Velocity of Limb	*C—O*	δ	Mean Velocity of Ring	*C—O*
Tenth-meters	Tenth-meters	° ′	Kilometers	Kilometers	Millimeters	Kilometers	Kilo-meters
5324.3	27.55	2 11	6.62	+3.67	0.0468	19.03	—0.25
5328.4	27.65	3 19	10.09	+0.20	0.0412	16.81	+1.97
5371.6	28.77	2 42	8.47	+1.82	0.0436	18.35	+0.43
5383.5	29.09	3 13	10.19	+0.10	0.0420	17.84	+0.94
5429.9	30.37	3 49	12.51	—2.22	0.0468	20.56	—1.78
			9.58	+0.71		18.52	+0.26

The results from both photographs are

Velocity of limb $= 10.3 \pm 0.4$ kilometers,

Mean velocity of ring $= 18.0 \pm 0.3$ kilometers;

the computed values being 10.29 and 18.78 kilometers respectively.

Although there seems to be no systematic difference between the two plates, the results for each differ by more than the probable error. With photographs on so small a scale, distortions of the lines are produced by the irregular deposit of even a few particles of silver; hence it is advisable to measure a large number of lines instead of multiplying observations on a few of them.

The number of lines in the table is however sufficient for the present purpose.

As I have already pointed out, it is necessary to guide the telescope with extreme accuracy in making such photographs as those described in the present paper, and the method which I have used is so simple and effective that a short account of it may be of interest.

The spectroscope is fully described in *Astronomy and Astro-Physics*, **12**, 40, January, 1893, and the prism-train used in these observations is there shown in Plate VII. The slit is observed during an exposure by a small "broken" telescope, which receives the rays reflected from the first surface of the prism nearest to the collimator.

To prepare for an observation of Saturn, the slit is shortened until its length is equal to the computed length of the image (major axis of the ring). A small bar, which is wider at one end than at the other, is cut out of thin metal, and placed across the field of the diagonal telescope. If the bar is approximately of the right width, then, by throwing the image of the slit a little above or below the center, and by rotating the eyepiece, which carries the bar with it, the bar can be made to very nearly cover the image, leaving a very short length of slit uncovered at each end. When the telescope is directed to Saturn the extreme ends of the ring appear from behind the (invisible) bar as two minute points or stars, and the attention of the observer is concentrated on keeping these stars equally bright. Any displacement in declination is indicated by their disappearance or unusual faintness. The photographs show that the guiding by this method is quite accurate. The spectra of the ansæ do not show any traces of the Cassini division, but it would probably be requiring too much to expect that they should do so, considering the small size of the image and the length of the exposure.

It is a question whether these observations could be better made with a larger telescope. If the same spectroscope were mounted on a large telescope, the width of the photographed spectrum would be greater, the lines would be longer, and their direction could be more definitely measured. On the other hand, the inclination of the lines would be diminished, since tan ϕ varies inversely with ρ, and it could not be increased by employing a greater dispersion, as the brightness of the spectrum, which would be the same for both telescopes, would hardly bear any further reduction. A material advantage would be that with the same slit-width a smaller area of the image would be included between the jaws, and hence at any part of the slit there would be fewer points having different velocities in the line of sight. On the whole, it seems to me that the advantage would lie with the large telescope. With a reflector, or a photographically corrected refractor, the photographs could be taken at the $H\gamma$ line,

where the dispersion is more than twice as great as in the region near λ 5350, and the only difficulty in that case would be found in the yellow color of Saturn.

I have given a somewhat full account of these observations, partly because of the interest inherent in everything that relates to the magnificent system of Saturn, and partly because the successful application of the spectroscope to the measurement of celestial motions depends largely upon details of appliances and methods.

REMARKS ON PROFESSOR E. C. PICKERING'S ARTICLE, "COMPARISON OF PHOTOMETRIC MAGNITUDES OF THE STARS," IN *A. N.* 3269.[1]

By G. MÜLLER and P. KEMPF.

IN No. 3269 of the *Astronomische Nachrichten*, Professor E. C. Pickering has published a paper in which special consideration is given to 38 stars—the stars being those which we had arranged in a separate table[2] in our *Photometric Durchmusterung*, because our value of their brightness differs by at least half a magnitude from that of the Cambridge catalogues or the *Uranometria nova Oxoniensis*. The entire method of treatment in this paper, and the conclusions which Pickering has arrived at and given in connection with his discussion, must produce the impression that the comparison of these few stars is to be regarded as a sufficient basis for estimating the relative accuracy of the different photometric catalogues in question. This impression is still further strengthened by the *49th Annual Report of the Harvard College Observatory*, which has just appeared, and in which the 38 stars are again considered. Here it is also directly stated that the differences found for these stars serve to indicate the relative accuracy of the catalogues referred to. A table is appended to the report in which the catalogues are arranged in the "order of excellence," and the discrepancies found for the 38 stars are represented graphically. The result at which Pickering arrives is that the Cambridge catalogue exceeds all of the others in reliability.

Even if it were not apparent that no conclusion can be drawn from such a small number of stars as this as to the degree of accuracy of a list containing several thousand stars, we should not wish to leave Pickering's article unanswered, especially since we cannot by any means approve of the method of treatment which he has applied to even the 38 stars in the comparison.

[1] Translated from *A. N.* 3279 at the request of Professor H. C. Vogel.

[2] *Publ. d. Astrophys. Obs. zu Potsdam*, **9**, 500.

Pickering has considered in all five different catalogues, those of Oxford and Potsdam, and three others, all of which are Cambridge catalogues. These last are the *Harvard Photometry*, the revision of the *Bonn Durchmusterung* (*Harvard Annals*, Vol. XXIV), and a revision of the *Harvard Photometry* which has not yet been published.

It is first of all to be remarked that 9 of the 38 stars cannot be employed in the investigation, since they are included in only two of the catalogues. The brightness of three of these stars as given in his table is, moreover, admitted by Pickering himself to be erroneous, for he assumes that the stars No. 1698 and No. 1699 have been transposed in consequence of a misprint, and, in the case of No. 1218, for which the difference "Potsdam — Pickering" reaches the value of 1.34 magnitude, he considers that the observation undoubtedly applies to some other star. Moreover, a lack of uniformity is still found in the 29 remaining stars, inasmuch as some of them occur in only three, others in four, and only nineteen in all five catalogues. Nevertheless Pickering takes for each star the mean of such values as are given, and regards the residuals obtained by comparison with this mean value as a criterion for the accuracy of the different catalogues.

Such a procedure could be regarded as justified in a certain sense, only in case the differences between the individual catalogues could be regarded as purely accidental and not in any way systematic. But since a glance at the separate columns of Pickering's table shows that there is a marked preponderance of one algebraic sign, and since it has moreover been shown in a previous comparison[1] of the *Harvard Photometry* and the *Uranometria nova Oxoniensis* that there is a systematic difference between these two catalogues, the method of treatment adopted by Pickering can hardly be regarded as applicable.

The comparison in Pickering's article is interesting to us because we learn in it that he has lately reobserved the 29 stars above referred to, and that his new measures agree so well with our own that the mean discrepancy is now only $\pm$ 0.18 magnitude, while the difference exceeds 0.5 magnitude in only one

[1] *V. J. S. der astron. Gesellschaft*, **21**, 257.

case.[1] This we regard as the best kind of proof that the originally large number of differences greater than 0.5 is in the great majority of cases not to be attributed to our catalogue. An explanation is perhaps still required for the stars 245, 1813, 2326 and 2395, for which the *mean* values in the different catalogues of Pickering differ by from 0.63 to 0.86 magnitude, and further for the stars 122, 185, 653, 3327, 3361. These last five stars are found in Vol. XXIV of the *Harvard Annals*, not only in the principal catalogue (Table I), but in the "Miscellaneous Measurements" (Table IV), and Pickering has used the mean of the values in the two tables. Now since it is expressly stated in Vol. XXIV, p. 202, that "When a star was found to be common to Tables I and IV, all of the observations were generally transferred to Table I," it seems to us that the value in Table I only should be used. By taking into account the values in Table IV, Pickering obtains further mean values which agree with our own to within allowable limits (there remains only one difference greater than 0.3), so that for these stars also the responsibility for the large discrepancies must be borne by the *Photometric Revision*.

We believe we have sufficiently proved in the preceding paragraphs that Pickering's conclusion, based on the comparison of a few stars, that the photometric catalogue of the Harvard Observatory is superior to all others, is quite untenable; we shall, however, on our side take this opportunity to make some general remarks on the photometric investigations at Cambridge, for which the contents of Pickering's article give the occasion.

In our *Photometric Durchmusterung* we have already subjected the Cambridge catalogues to a stringent criticism and have brought forward everything that can be said for or against them. We only desire here to again state, and with even stronger emphasis, that in our opinion the Cambridge catalogue will always have a high value because it gave for the first time a systematic catalogue of the magnitudes of a large number of stars, but that on the other hand it has not that degree of accuracy which must be

[1] The star No. 653, the striking color of which (G R) at once accounts for the large discrepancy.

striven for with the instrumental means of today, and which can in fact be attained. The reasons for this opinion rest upon the following considerations:

The most reliable criterion for the excellence of photometric observations is afforded by the agreement of the values obtained on different evenings for the brightness of the same star. That the probable error ± 0.15 of one observation in the *Harvard Photometry* is rather large may be sèen from the fact that the same error for the Potsdam measures is ± 0.06. The number of observations for each star at Cambridge is not so much greater than at Potsdam as to reduce the larger uncertainty of the separate measurements to approximate equality in the final results. The average probable error of a catalogue brightness is for Cambridge ± 0.075 and for Potsdam ± 0.040. But if the individual stars of the *Harvard Photometry* are considered, it will be found that differences of the values obtained on different nights, amounting to a whole magnitude or more, occur in the case of more than 400 stars (out of 4260), *i. e.*, in about one star in ten. For 170 stars it even happens that one and sometimes even several measures differ *from the mean* of the others by more than a whole magnitude. These observations are simply rejected. In the *Photometric Revision* the limits of permissible discordance are drawn somewhat closer, in consequence of which 550 measurements in all, differing from the mean of the other observations by at least 0.6 magnitude, are rejected. It is evident that so high a percentage of entirely erroneous measurements ought not to occur, and that measurements of one and the same star which differ by a whole magnitude deserve little confidence. When Pickering asserts in his article that the accidental errors of observation are of little importance, and then adds, "At Harvard, when an observation was discordant, the star was reobserved on so many nights that the final value was generally only changed one or two-tenths of a magnitude whether the observation was retained or rejected," we desire to say, on our part, that such a degree of accuracy in photometric measurements seems to us to be entirely inadequate. Observations of so small reliability as this are in

no way preferable to mere estimates of brightness, in which much better results can easily be obtained by a practiced observer.

As an explanation of the above characteristic discordances there only remains, in our opinion, one of the following assumptions: Either the stars concerned are variable, or the atmospheric conditions on one or the other of the evenings were not above suspicion, or finally, mistakes have been repeatedly made in the identification of stars. There are no other explanations for such enormous differences in photometric measurements, and since the first two assumptions are very improbable when a considerable number of stars is in question, we are forced to ascribe the greater part of the decidedly erroneous observations in the Cambridge catalogue to the cause last mentioned. We must again emphasize the opinion which we have already expressed in our *Durchmusterung* that the Cambridge measurements have been made in far too great haste to exclude the possibility of frequent erroneous identifications of stars, and this opinion is not shaken by the closing remarks in Pickering's article. We admit that in specially favorable cases observations of a few stars can be made at the rate of one every minute, but we regard it as inconceivable that the same rapidity can be maintained as an average for a large number of stars without laying the certainty of their identification open to question. We cannot regard as advantageous the measurement by one and the same observer of 63 stars in 59 minutes (*Harvard Annals*, XIV, series 512), of 201 stars in 195 minutes (XXIII, series 1015) or of 87 stars in 44 minutes (XXIII, series 930); and when finally 61 stars are observed in 26 minutes (XXIII, series 942), the interval of 26 seconds available for each star is hardly sufficient for setting the photometer with proper care, leaving no time whatever for a certain identification of the star. While it is true that rapid procedure is attended with certain advantages from a quantitative standpoint, allowing, for example, a surprisingly quick survey of the whole heavens to be made, it is quite unavoidable that when observations are made with such haste as this, the quality of the results must suffer in a not inconsiderable degree.

MINOR CONTRIBUTIONS AND NOTES.

THE SHORT WAVE-LENGTHS OF THE SPARK SPECTRUM OF ALUMINIUM.

I HAVE lately determined the short wave-lengths of the aluminium spark by means of a short-focus Rowland concave grating. They were photographed in the second order together with the overlapping part of the first order of the spectrum of iron. Many of the iron lines in this part are included in Rowland's new table of standard wave-lengths.[1] From these the wave-lengths of the aluminium lines were interpolated.

The photographs were taken *in vacuo* and in air of atmospheric pressure on plates prepared by Professor Kayser according to Dr. V. Schumann's process:[2]

760mm of mercury and 20° C.	In vacuo	Previous determinations by Cornu [3]
1854.09	1854.77	1852.2
1862.20	1862.81	1860.2
1935.29	1935.90	1933.5
1989.90	1990.57	1988.1

There is another weak aluminium line at about λ 1930.4, which I have not tried to measure more accurately as it is rather diffuse. Cornu makes it λ 1928.7. The mean error of my determinations, which are the results of six exposures, is less than 0.014.

C. RUNGE.

TECHNISCHE HOCHSCHULE,
Hannover, Germany.

A LARGE ERUPTIVE PROMINENCE.

ON the morning of March 25, 1895, while observing the chromosphere and prominences, my assistant, Mr. Ferdinand Ellerman, noticed at $9^h\ 50^m$ a rather bright prominence about 2′ high at position angle

[1] *A. and A.* **12**, 1893.

[2] V. SCHUMANN: *Sits. Ber. der Wiener Akad.* October, 1893.

[3] CORNU: *Jour. de Phys.* **10**, 425, 1881.

238°. At 10^h 20^m the *Hα* line was displaced toward the red, and the height of the prominence had visibly increased. Preparations were at once made to photograph the prominence with the spectroheliograph attached to the 12-inch telescope. The first exposure was made at 10^h 34^m on plate D 3625, and a second was made on the same plate at 10^h 40^m. At 10^h 46^m a marked displacement toward the blue was noticed in the upper part of the prominence, which had now reached a height of about 7′. A third exposure was made at 10^h 58^m, when the prominence had probably attained its greatest height. At 11^h 6^m the upper parts had disappeared, and the *Hα* line could be traced to a distance of only about 4′ from the limb. It was displaced strongly toward the blue at a point near the base of the prominence.

The three photographs obtained have been reproduced in Plate XV, enlarged 3.3 diameters. On this scale the diameter of the Sun would be 6.6 inches. Measurements of the negatives give the following results:

No.	Time[1]	Height (K line)	
1	10^h 34^m	300″	135,200 miles
2[2]	10^h 40^m	359″	161,500 "
3	10^h 58^m	624″	280,800 "

The times given for each photograph were noted when the moving slit of the spectroheliograph had reached a position about 4′ from the Sun's limb. On account of the slow motion of the slit, and the nature of the phenomenon the times thus obtained cannot be relied upon to determine the velocity of ascent with accuracy. I hope to have in operation soon an apparatus capable of giving complete and exact records of such eruptions.

Mr. Ellerman observed no indication of disturbance on the Sun's disk near the position angle of the prominence, and photographs taken after the eruption showed no bright faculæ at this point on the limb.

George E. Hale.

[1] Chicago Mean Time.

[2] During this exposure the base of the prominence was accidentally covered by the circular metallic disk used to exclude from the spectroheliograph the direct light of the photosphere.

ON A PHOTOGRAPHIC METHOD OF DETERMINING THE VISIBILITY OF INTERFERENCE FRINGES IN SPECTROSCOPIC MEASUREMENTS.

IN a theoretical investigation of the relation between the distribution of light in a source as a function of the wave-length, and the resulting "visibility curve,"[1] Professor Michelson has adopted for his definition of "visibility"

$$V=\frac{I_1-I_2}{I_1+I_2}$$

where I_1, I_2 are respectively the intensities at the centers of adjoining bright and dark interference bands. The curves obtained in the work with the interferential refractometer have been platted directly from eye-estimates of the visibility. That such estimates are reliable has been clearly shown by Professor Michelson in his important memoir "On the Application of Interference Methods to Spectroscopic Measurements."[2] Two quartz lenses, one concave and the other convex, and of equal curvatures, were mounted with their axes crossed at right angles between two Nicol prisms. The visibility of the concentric system of interference rings thus produced depends upon the angles between the axis of the quartz and the polarizer and analyzer. If the analyzer and polarizer are parallel Professor Michelson has shown that

$$V=\frac{I_1-I_2}{I_1+I_2}=\frac{1-\cos^2 2a}{1+\cos^2 2a},$$

where a is the angle between the axis of the first quartz and the principal plane of the polarizer.

This curve, when platted together with the mean of a number of eye-estimates, showed that the error of an estimate was never greater than 0.16, while in most cases it was much less than this. "The curves show a general tendency to estimate the visibility too high when the interference bands are clear, and too low when they are indistinct. This tendency may be modified by a number of circumstances—thus, it increases with the refrangibility of the light used; it is greater when the field contains a large number of bands than when they are but few; it is greater while the visibility curve is falling than when it is rising; it does not seem to be greatly affected by the intensity of the light;

[1] *Phil. Mag.* April, 1891.

[2] *Smithsonian Contributions to Knowledge*, No. 842.

finally, it varies on different occasions and with different observers. Notwithstanding these disturbing causes, the result, after applying the correction, will rarely be in error by more than one-tenth of its value, and ordinarily the approximation is much closer than this."[1]

There can thus be no doubt that in most applications of interference methods, especially in the laboratory, where the source of light is under control, the visibility can be estimated by an experienced observer with a sufficient degree of accuracy. Professor Michelson has in fact found that no advantage results from matching the fringes with a system of artificial fringes in the same field of view, whose visibility for any value of the angle α can be taken from a table. The loss of time, and the difficulty likely to result from variations in the source of light, are not accompanied by a corresponding increase in the accuracy of the measures.

In the infra-red Professor Wadsworth has found that the intensity of the fringes can be measured with a bolometer, and a fluorescent eye-piece would probably suffice for visual observations of the fringes in the lower part of the ultra-violet. In certain cases, however, photographic methods seem to offer important advantages.

In his investigations on elliptic polarization Professor Cornu employed photography to record interference fringes obtained with ultra-violet light.[2] A similar method can be very easily applied to determine the visibility of the fringes in spectroscopic measurements. In my experiments an electric arc taken between horizontal carbon poles has served as the source of light. An image of the arc is formed on the slit of a concave-grating spectroscope, mounted according to Rowland's well-known plan. The second order spectrum of a four-inch grating of ten-feet focus, ruled with 14,438 lines to the inch, is employed. A small interferential refractometer, similar to that described in the papers referred to above, was very kindly loaned to me by Professor Michelson. The light from a spectral line enters the apparatus through the slit of a small collimator, and finally falls upon a photographic plate at the focus of a short telescope. The fringes produced with various differences of path have been photographed with the light of several lines in the blue part of the spectrum. In spite of the great dispersion the exposures need not exceed ten or fifteen seconds. The field occupied by the fringes may be widened by

[1] *l. c.* p. 6.

[2] *C. R.* **108**, 917. See also *Eder's Jahrbuch für Photographie*, 1891.

opening the first slit of the spectroscope, or, if this is impracticable, by moving the collimator lens until the narrow second slit is well out of focus.

The intensity (and hence the visibility) of the fringes can be determined from the photographs in a variety of ways. For instance, it may be estimated directly, or measured with some form of photometer, or determined by comparison with a standard set of photographed fringes obtained with quartz lenses and Nicols.

It is probable that the photographic method will be found to be of value in astrophysical work. Observations of the Sun and other heavenly bodies, made at the Kenwood Observatory with apparatus similar to that employed with such marked success by Professor Michelson in his interference studies of the spectra of the elements, will be described in a future paper. The fringes have been observed without difficulty in the $H\alpha$ line of solar prominences, and in this case their visibility can be sufficiently well estimated. For the H and K lines photography will probably give better results. As the time of exposure need not be more than a few seconds, the whole process may be conducted automatically. It is only necessary to arrange a simple series of mechanical or electrical motions to make the exposure, move the screw of the refractometer any desired fraction of a turn, and move the photographic plate far enough to allow another exposure to be made upon it. The observer is thus left free to keep the prominence in the proper position on the first slit of the spectroscope.

It is doubtful whether the fringes could be observed directly in the H and K reversals on the solar disk. In any case it would be extremely difficult, if not impossible, to estimate their visibility with any degree of accuracy. Although the experiment has not yet been tried, it seems barely possible that the visibility curves for these reversals can be determined by photography.

In the only attempt yet made to observe the fringes in the chief line of the Orion nebula spectrum it was impossible to see them. The apparatus was, however, a temporary one, and the silvered mirrors were greatly tarnished. Even if the fringes could be seen it would hardly be possible to estimate their visibility, on account of their faintness. But it is probable that, with suitable apparatus, the fringes could be photographed, provided the temperature were constant during the long exposure required. For such work it might be desirable to employ a refractometer with one of its mirrors cut into a

number of pieces, each of them adjusted to give a different length of path. Thus one or two exposures would suffice to determine the visibility curve of the line in question. GEORGE E. HALE.

March 18, 1895.

NOTE ON THE EXPOSURE REQUIRED IN PHOTOGRAPHING THE SOLAR CORONA WITHOUT AN ECLIPSE.

IN a recent article "On some Attempts to Photograph the Solar Corona without an Eclipse"[1] I described the Huggins apparatus of the Observatory on Mount Etna, and referred to some experiments made with it with the object of ascertaining the exposures required for the Moon and the solar corona respectively. The corona-like images obtained with this apparatus did not appear to me (or to Professor Riccò[2]) to represent the true corona. Among the reasons advanced in support of this conclusion was one that I have since found to be inconclusive. I therefore desire in the present note to modify my previous statement.

It seemed to Professor Riccò and myself that the extremely short exposure required with the Huggins apparatus must be altogether insufficient to cause any impression of the coronal image upon the photographic plate, because with the same apparatus the corona could not be photographed during an eclipse with many times this exposure. As the brightest parts of the corona probably exceed the Moon in brightness, experiments in photographing the Moon at night sufficed to establish the truth of this last assertion. We overlooked the fact, however, that the Moon can be photographed in the daytime with an exposure much shorter than that required at night. At the Lick Observatory Mr. S. W. Burnham photographed the Moon in daylight with an aperture of $\frac{f}{70}$ and an exposure of $\frac{1}{100}$ second.[3] Using the same ratio of focal length to aperture, and a plate of the same make and sensitometer number, we have recently been unable to obtain any image of the Moon in the first quarter with an exposure less than $\frac{1}{2}$ second.

It thus appears that though a feeble light acting upon a photographic plate during a given time may produce no developable image,

[1] *A. and A.* October, 1894.

[2] See this JOURNAL, January, 1895.

[3] *Lick Observatory Report on the Total Eclipse of January 1, 1889*, p. 14.

yet the same light acting upon the same plate during a much shorter time may produce a developable image, provided only that the plate be illuminated during the exposure by a second luminous surface superposed upon the first. In order that the image of the first source may be visible on the photograph it must exceed the background in density by at least one part in sixty (roughly).

Unfortunately the conclusions reached by Professor Riccò and myself cannot be sensibly modified by recognition of these facts. The independent evidence advanced in the papers mentioned is probably sufficient to prove that the corona has not hitherto been photographed without an eclipse. The sky near the Sun is so bright that the density of the deposit produced by it is not visibly increased by the additional deposit due to the comparatively feeble light of the corona.

George E. Hale.

TERRESTRIAL HELIUM (?).

The following papers by Professor Ramsay and Mr. Crookes were communicated to the Chemical Society at its anniversary meeting. Professor Ramsay's paper was as follows: In seeking a clue to compounds of argon, I was led to repeat experiments of Hillebrand on clèveite, which, as is known, when boiled with weak sulphuric acid, gives off a gas hitherto supposed to be nitrogen. This gas proved to be almost free from nitrogen; its spectrum in a Plücker's tube showed all the prominent argon lines, and, in addition, a brilliant line close to, but not coinciding with, the D lines of sodium. There are, moreover, a number of other lines, of which one in the green-blue is especially prominent. Atmospheric argon shows, besides, three lines in the violet which are not to be seen, or, if present, are excessively feeble, in the spectrum of the gas from clèveite. This suggests that atmospheric argon contains, besides argon, some other gas which has as yet not been separated, and which may possibly account for the anomalous position of argon in its numerical relations with other elements.

Not having a spectroscope with which accurate measurements can be made, I sent a tube of the gas to Mr. Crookes, who has identified the yellow line with that of the solar element to which the name

"Helium" has been given. He has kindly undertaken to make an exhaustive study of its spectrum.

I have obtained a considerable quantity of this mixture, and hope soon to be able to report concerning its properties. A determination of its density promises to be of great interest.

The spectrum of the gas was next discussed by Mr. Crookes, who said: By the kindness of Professor Ramsay I have been enabled to examine spectroscopically two Plücker tubes filled with some of the gas obtained from the rare mineral clèveite.[1] The nitrogen had been removed by "sparking." On looking at the spectrum, by far the most prominent line was seen to be a brilliant yellow one apparently occupying the position of the sodium lines. Examination with high powers showed, however, that the line remained rigorously single when the sodium lines would be widely separated. On throwing sodium light into the spectroscope simultaneously with that from the new gas, the spectrum of the latter was seen to consist almost entirely of a bright yellow line, a little to the more refrangible side of the sodium lines, and separated from them by a space a little wider than twice that separating the two sodium components from one another. It appeared as bright and as sharp as D_1 and D_2. Careful measurements gave its wave-length 587.45; the wave-lengths of the sodium lines being D_1, 589.51, and D_2, 588.91. The differences are therefore—

	Wave-lengths	Differences
D_1 - - -	589.51	
		0.60
D_2 - - - -	588.91	
		1.46
New line - - -	587.45	

The spectrum of the gas is, therefore, that of the hypothetical element helium, or D_3, the wave-length of which is given by Angström as 587.49, and by Cornu as 587.46.

Besides the helium line, traces of the more prominent lines of argon were seen.

Comparing the visible spectrum of the new gas with the band and line spectrum of nitrogen, they are almost identical at the red and blue end, but there is a broad space in the green where they differ entirely. The helium tube shows lines in the following positions:

[1] Clèveite is a variety of uraninite, chiefly a uranate of uranyle, lead, and the rare earths. It contains about 13 per cent. of the rare earths, and about 2.5 per cent. of a gas said to be nitrogen.

		Wave-lengths	
(*a*)	D_3, yellow	587.45	Very strong. Sharp.
(*b*)	Yellowish green	568.05	Faint. Sharp.
(*c*)	Yellowish green	566.41	Very faint. Sharp.
(*d*)	Green	516.12	Faint. Sharp.
(*e*)	Greenish blue	500.81	Faint. Sharp.
(*f*)	Blue	480.63	Faint. Sharp.

I have taken photographs of the spectrum given by the helium tube. At first glance the ultra-violet part of the spectrum looks like the band spectrum of nitrogen, but closer examination shows considerable differences. Some of the lines and bands in the nitrogen spectrum are absent in that from the helium tube, whilst there are many fine lines in the latter which are absent in nitrogen. Accurate measurements of these lines are being taken.

We reprint from *Nature* the above account of Professor Ramsay's supposed discovery of terrestrial helium, and Mr. Crookes' measures of the lines in the spectrum of the new gas. An examination of the measures is sufficient to show that the identification of the bright yellow line with the D_3 line cannot yet be considered certain. The following measures from Rowland's table of standard wave-lengths will be of interest for comparison with the results obtained by Crookes.

	Wave-lengths	Differences
D_1	5896.154	
		5.972
D	5890.182	
		14.200
D_3	5875.982	

In a note accompanying Rowland's measure of the D_3 line it is remarked that "this value of the wave-length of D_3 is the result of three series of measurements made with a grating having 20,000 lines to the inch, and is accurate to perhaps 0.02."

Mr. Crookes' value for the difference D_1–D_2 is 6.0 tenth-meters; this is in close agreement with Rowland's value of 5.972. But the difference D_2– New Line, determined by Crookes to be 14.6 tenth-meters, agrees very poorly with Rowland's value of 14.200 tenth-meters for the difference D_2–D_3. Whether this discrepancy can be accounted for by the comparatively low dispersion probably used by Mr. Crookes remains to be seen.

A LARGE REFLECTOR FOR THE LICK OBSERVATORY.

MR. EDWARD CROSSLEY, of Halifax, England, proposes to present to the Lick Observatory the three-foot reflecting telescope and its dome, which now form part of his private observatory. The grateful thanks of the Lick Observatory are offered to him for this most generous and highly appreciated gift.

EDWARD S. HOLDEN.

MOUNT HAMILTON,
April 4, 1895.

Change of Address.—The attention of contributors to THE ASTROPHYSICAL JOURNAL is called to the fact that after June 15, 1895, my permanent address will be *Yerkes Observatory, Lake Geneva, Wisconsin.* All papers for publication and correspondence relating to contributions and exchanges as well as all personal communications should be sent to this address.

GEORGE E. HALE.

Reviews.

THE SPECTRUM RESEARCHES OF PROFESSOR J. M. EDER AND E. VALENTA.

DURING the past five years there has been appearing in the *Denkschriften der mathem. naturw. Cl. der Kais. Acad. der Wissensch. in Wien* a most important series of papers on spectrum analysis by Professor Josef Maria Eder. In 1893 he associated with himself in his work Mr. E. Valenta, and all recent papers have been signed by both authors.

What makes the work of Eder and Valenta especially interesting is the fact that their aim has been not to measure the wave-lengths of any one substance with extreme accuracy, but rather to investigate modifications in the spectra of any substance under varying conditions and to study the spectra of different compounds of the same element, especially in the ultra-violet. Their work has been done with extreme care, and the conclusions reached are most important.

The general method used was to photograph the spectrum under investigation and a comparison spectrum of known substances on the same plate, the comparison spectrum being along the middle of the plate and the other along the two edges. Then, by micrometer measurements and a process of interpolation, the wave-lengths could be measured. The lenses and prism of the spectroscope were quartz; and the photographic plate was so turned oblique to the axis of the "telescope-arm" that it was possible to bring the entire spectrum from $\lambda 2000$ to $\lambda 7600$ in perfect focus on one plate. Eye observations were of course made in the longer wave-lengths. The comparison spectrum generally used was that of the spark discharge between poles made of an alloy containing lead, cadmium and zinc. The iron spectrum was found to contain too many lines for convenient use. The wave-lengths of the various reference lines were at first those given by Hartley and Adeney; but later, after the publication of Kayser and Runge's measurements, the wave-lengths were reduced to Rowland's scale.

Eder's first paper,[1] in 1890, is on the subject of the spectrum of burning hydrocarbons; and he used for this purpose the blue flame of the Bunsen burner. He observed of course the well-known carbon

[1] *Wien. Denkschr.* 1890.

bands; but in addition discovered several new ones. He found two sets of bands in the same spectrum; one set, the familiar one which appears in the arc-spectrum, has the edges towards the red; the other set (first observed by Eder) has the edges towards the shorter wave-lengths and always has a single isolated line near the head of each band. He notes that these new bands do not coincide with the "cyanogen bands," so-called. In this same paper he mentions some observations on the spectrum of water vapor at two different temperatures, that of the Bunsen flame and that of the oxyhydrogen flame. At the lower temperature the two bands at λ 3064 and λ 2811 appear; and at the higher temperature, two other bands, further in the ultra-violet. These bands, as is well known, have their edges towards the shorter wave-lengths.

In his second paper[1] Eder gives the results of his investigations of the spectrum of the ammonia-oxygen flame, *i. e.* of ammonia burning in an atmosphere of oxygen. He found that it consisted of a series of bands whose edges were all turned towards the red.

In January, 1893, Eduard Valenta's name became associated with Eder's in a paper[2] of great interest on the spark spectrum of carbon under various conditions. There was some difficulty in making pure carbon conducting; but this was finally overcome by a method described by Bunsen. Then, by a most ingenious arrangement, sparks were passed between carbon electrodes, dry or wet, in atmospheres of hydrogen, carbon-dioxide and air. When the spark is passed between the two poles in hydrogen, the smallest number of lines appear in the spectrum, because in other atmospheres like CO_2, or air, the gas is dissociated and various other spectra appear. This fact is of interest as indicating the best method of getting spark-spectra of other substances, such as sodium; the carbon poles can be moistened in a solution of common salt and then placed in an atmosphere of hydrogen. If sparks are now passed, the carbon offers the least possible complication. In all the spark-spectra of carbon there were certain characteristic lines present which did not belong to the "carbon bands" or to the "cyanogen bands," and these were carefully measured and described. This spark-spectrum of carbon is in some respects its fundamental one. The carbon bands were generally present also; and so were some of the "cyanogen bands" unless the carbon poles were entirely free from air.

In this same paper the spark spectrum of silicon is given. It was

[1] *Wien. Denkschr.* 1890. [2] *Ibid.* 1893.

obtained in two ways: one by causing sparks to pass between small crystals of silicon imbedded in platinum, and then correcting for the platinum lines; the other by causing sparks to pass between poles of carbon moistened with silicon-chloride. There were certain differences observed between the spectra obtained in these two ways, especially in the broadening of certain lines and in the relative intensity of the lines.

In the fourth paper[1] the spark-spectrum of boron is given. It was obtained by causing sparks to pass between crystals of boron imbedded in lead; and it was found to contain twenty-two lines, lying between λ 3960 and λ 2000. The two chief lines are at λ 2497.7 and λ 2496.8, and evidently coincide with the only two lines in the arc-spectrum at λ 2497.82 and λ 2496.87 as measured by Rowland and Tatnall.

In the fifth paper[2] a description is given of the flame-spectra of potassium, sodium, lithium, calcium, strontium, barium and boracic acid. The general method used was to feed automatically a Bunsen burner with salts of these substances, and to photograph the spectra. Sometimes as much as thirty hours' exposure was required. Many lines, known in the arc-spectrum, but never before seen in the flame-spectrum, were observed and measured. Besides these line-spectra, continuous spectra were produced by potassium, sodium and lithium. And along with the metallic lines of calcium, strontium and barium, band-spectra of their compounds were observed, the most prominent of these being oxide bands. Chloride bands were also produced and measured. All of these bands as well as those of boracic acid lie mainly in the visible spectrum, pointing to a low temperature.

In the sixth paper,[3] the ultra-violet absorption of different kinds of glass is recorded. Nine kinds of colorless Jena glass, cut in sections of 1^{mm} and 1^{cm} thickness were first investigated. One particular kind of light phosphate-crown glass was found to have practically no absorption as far as λ2500. The absorption of some sixteen kinds of colored glass was also studied with special reference to the connection between the positions of the absorption bands and the refractive powers. Kundt's law that "the absorption bands move towards the red end of the spectrum as the refractive power of the solvent increases" was found to hold for many cases.

The seventh paper[4] contains the comparison of the spectra of potassium, sodium and cadmium in the flame, the arc and the spark. The

[1] *Wien. Denkschr.* 1893. [2] *Ibid.* 1893. [3] *Ibid.* 1894. [4] *Ibid.* 1894.

flame has a temperature of about 1000° C.; the temperature of the arc cannot be far from 3500° C.; and probably the temperature of the spark (if it has such a property as a definite temperature) is very high. There were observed four lines in the flame-spectrum of sodium and twelve in that of potassium. These lines are by far the most prominent in the arc-spectra, and are usually easily reversed there. Many more lines appear in the arc-spectrum and all of these, with still more, appear in the spark-spectrum. The prominent lines in the arc-spectrum continue to be the most prominent in the spark-spectrum. The case is entirely different with cadmium (as it is also for zinc). Some of the chief lines in the arc-spectrum are not present in the spark-spectrum, and *vice versa*. Owing to this fact some mistakes were made by Kayser and Runge in identifying certain lines of cadmium selected by Mascart as standard lines. Mascart used the spark-spectrum and Kayser and Runge the arc. This error is pointed out and corrected in this paper by Eder and Valenta. Lines which are similar or belong to the same series ought to have like changes as the temperature of the spectrum is changed.

Probably the most interesting paper of all is the last one of July 5, 1894. This deals with the different spectra of mercury. Observations on the arc and spark-spectra and on the ordinary Geissler tube discharge showed that all three were alike, the most prominent lines in one spectrum being also the most prominent in the others. But two entirely new spectra were discovered. If mercury vapor is distilling at a low pressure through a capillary tube, and if a spark be passed through it, spectra are observed which are quite distinct from the ordinary one. If there is a large number of Leyden jars in circuit, the spectrum consists of an *immense* number of fine, sharp lines; but if there are no jars in circuit the spectrum is entirely changed; it becomes a series of bands whose edges are towards the red. One spectrum is just as complete as the other, neither one being a development of the other. The band spectrum corresponds to a trifle lower temperature than the new line spectrum; but it is difficult to see how complexity of molecular structure can account for the difference between the two spectra in the case of mercury, whose vapor is monatomic. This has, of course, a most important bearing on the theory of band and line-spectra, and seems to decide definitely against some of the present ideas concerning them.

J. S. AMES.

Recent Publications.

A list of the titles of recent publications on astrophysical and allied subjects will be printed in each number of The Astrophysical Journal. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

1. The Sun.

Adams, Alex. J. S. On the Connection between Variations of Terrestrial Magnetism and Solar Surface Disturbances. Jour. B. A. A. **5**, 260, 1895.

Brown, Miss E. Third Report of the Section for the Observation of the Sun. Mem. B. A. A. **3**, Part III, 49–120, 1895.

Lockyer, J. Norman. Observations of Sun-spot Spectra. Nat. **51**, 448–449, 1895.

Stratonoff, W. Bestimmung der Rotationsbewegung der Sonne aus Fackelpositionen. A. N. **137**, 165–167, 1895.

Tacchini, P. Osservazioni di protuberanze solari fatte al Regio Osservatorio del Collegio Romano nel 4° trimestre del 1894. Mem. Spettr. Soc. Ital. **24**, 18–20, 1895.

Tacchini, P. Macchie e facole solari osservate al Regio Osservatorio del Collegio Romano nel 4° trimestre del 1894. Mem. Spettr. Soc. Ital. **24**, 15–17, 1895.

3. Stars and Stellar Photometry.

Anderson, Th. D. New Variable Star in Lyra. A. N. **137**, 235, 1895.

Barnard, E. E. Filar Micrometer Measures of Nova Aurigæ in 1894. A. N. **137**, 233–234, 1895.

Holetschek, J. Beobachtungen des Veränderlichen W Aquilæ. A. N. **137**, 235–236, 1895.

Markwick, E. E. On a New Variable Star in Centaurus. Jour. B. A. A. **5**, 247–249, 1895.

Maunder, E. Walter. The Southern Milky Way with the Sydney Star Camera. Knowl. **18**, 87, 1895.

OUDEMANS, J. A. C. Ueber die Aenderung der Helligkeit der Fixsterne zufolge der eigenen Bewegung in der Richtung der Gesichtslinie. A. N. **137**, 169–171, 1895.

PARKHURST, HENRY M. Confirmations of Variability. A. J. No. 340, **15**, 32, 1895.

SCHUR, W. Ueber die Beobachtungen von Oertern der grossen Praesepegruppe durch photographische Aufnahmen. A. N. **137**, 221, 1895.

SKINNER, AARON N. New Variable in Cetus, *SDM*–15° 6531. A. J. No. 342, **15**, 48, 1895.

TISSERAND, F. Les variations de lumière de l'étoile Algol. Bull. Mens. Soc. Astr. France, **1**, 73–77, 1895.

WAUGH, W. R. Third Report of the Section for the Observation of Jupiter. Mem. B. A. A. **3**, Part IV, 121–150, 1895.

YENDELL, PAUL S. On the Variable Stars 7247 RX Cygni and 8116 W Cephei. A. J. No. 340, **15**, 30–31, 1895.

YENDELL, PAUL S. Observations of Variable Stars of Short Period during the Year 1894. A. J. No. 341, **15**, 39, 1895.

YENDELL, PAUL S. Observed Maxima and Minima of Long-Period Variables, 1894–1895. A. J. No. 341, **15**, 35, 1895.

YENDELL, PAUL S. Observations of Long-Period Variables. A. J. No. 340, **15**, 28–29, 1895.

4. STELLAR SPECTRA, DISPLACEMENTS OF LINES AND MOTIONS IN THE LINE OF SIGHT.

LEDUC, A. Note historique sur l'influence du mouvement de la terre sur les phénomènes de la réfraction. Jour. de Phys. **4** (3me Sér.), 106–109, 1895.

5. PLANETS, SATELLITES AND THEIR SPECTRA.

BUCHHOLZ, H. Ueber die Japetusverfinsterung durch Saturn und sein Ringsystem vom Jahre 1889. A. N. **137**, 241–271, 1895.

DESLANDRES, H. Recherches spectrales sur la rotation et les mouvements des planètes. C. R. **120**, 417–420, 1895.

ELGER, T. GWYN. Selenographical Notes. Obs'y **18**, 117, 157, 1895.

FAUTH, PH. Ueber die Verwerthung photographischer Mondaufnahmen. A. N. **137**, 203–205, 1895.

LOWELL, PERCIVAL. Mars — Oases. Pop. Ast. **2**, 343–349, 1895.

LYNN, W. T. Cassini and the Principal Division in Saturn's Ring. Obs'y **18**, 118–120, 1895.

POINCARÉ, H. Observations au sujet de la communication précédente de M. Deslandres. C. R. **120**, 420–421, 1895.

RICCÒ, A. Eclisse di Luna del 14-15 Settembre 1894, osservato nel Regio Osservatorio di Catania. Mem. Spettr. Soc. Ital. **24**, 12-14, 1895.

SEE, T. J. J. Peculiar Illumination of the Moon during the Total Eclipse of March 10. A. J. No. 341, **15**, 38, 1895.

————Neue Wahrnehmungen am Mondkrater Linné. Sirius, **23**, 50-56, 1895.

6. COMETS, METEORS AND THEIR SPECTRA.

HOLETSCHEK, J. Beobachtungen des Encke'schen Cometen 1895. A. N. **137**, 237-238, 1895.

HUSSEY, W. J. The Photography of Comets with Notes Concerning Comet Rordame. Pop. Ast. **2**, 353-358, 1895.

MONCK, W. H. S. The Radiant Points of Meteors. Jour. B. A. A. **5**, 253-256, 1895.

7. NEBULÆ AND THEIR SPECTRA.

HASSELBERG, B. Sur les observations spectroscopiques des nebuleuses faites à Mt. Hamilton à l'aide du grand réfracteur de l'Observatoire de Lick par James E. Keeler. Mem. Soc. Spettr. Ital. **24**, 1-11, 1895.

WOLF, MAX. Notiz über die Plejaden-Nebel. A. N. **137**, 175. 1895.

8. TERRESTRIAL PHYSICS.

CLAYTON, H. HELM. Eleven-year Sun-spot Weather Period and its Multiples. Nat. **51**, 436-437, 1895.

EDITOR OF *Nature*. The Aurora of March 13. Nat. **51**, 517-518, 1895.

LORD KELVIN. The Age of the Earth. Nat. **51**, 438-440, 1895.

9. EXPERIMENTAL AND THEORETICAL PHYSICS.

DEWAR, JAMES. Scientific Uses of Liquid Air. Roy. Inst. Proc. 13 pp., 1894.

RUBENS, H. Die Ketteler-Helmholtz'sche Dispersionsformel. Wied. Ann. **54**, 476-485, 1895.

11. PHOTOGRAPHY.

CRISWICK, G. S. Development of the Plates of the International Astrographic Chart. Jour. B. A. A. **5**, 245-247, 1895.

12. INSTRUMENTS AND APPARATUS.

GRUBB, SIR HOWARD. The Development of the Astronomical Telescope. Roy. Inst. Proc. 18 pp., 1894.

TAYLOR, H. DENNIS. An Experiment with a 12½-inch Refractor, whereby the Light lost through the Secondary Spectrum is separated out and rendered approximately measurable. Mem. R. A. S. **51,** Part IV., 77–86, 1895.

ZENGER, CH. V. L'objectif catoptrique et symétrique. C. R. **120,** 609–611, 1895.

13. GENERAL ARTICLES, MEMOIRS AND SERIAL PUBLICATIONS.

BERTHELOT. Essais pour faire entrer l'argon en combinaison chimique. C. R. **120,** 581–585, 1895.

BERTHELOT. Nouvelles recherches de M. Ramsay sur l'argon et sur l' hélium. C. R. **120,** 660–661, 1895.

BERTHELOT. Remarques sur les spectres de l'argon et de l'aurore boréale. C. R. **120,** 662, 1895.

RAMSAY, W. Terrestrial Helium (?). Nat. **51,** 512, 1895.

SIDGREAVES, W. Results of Meteorological, Magnetical and Solar Observations. Stonyhurst Coll. Obsy. 84 pp., 1894.

NOTICE.

The scope of THE ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects

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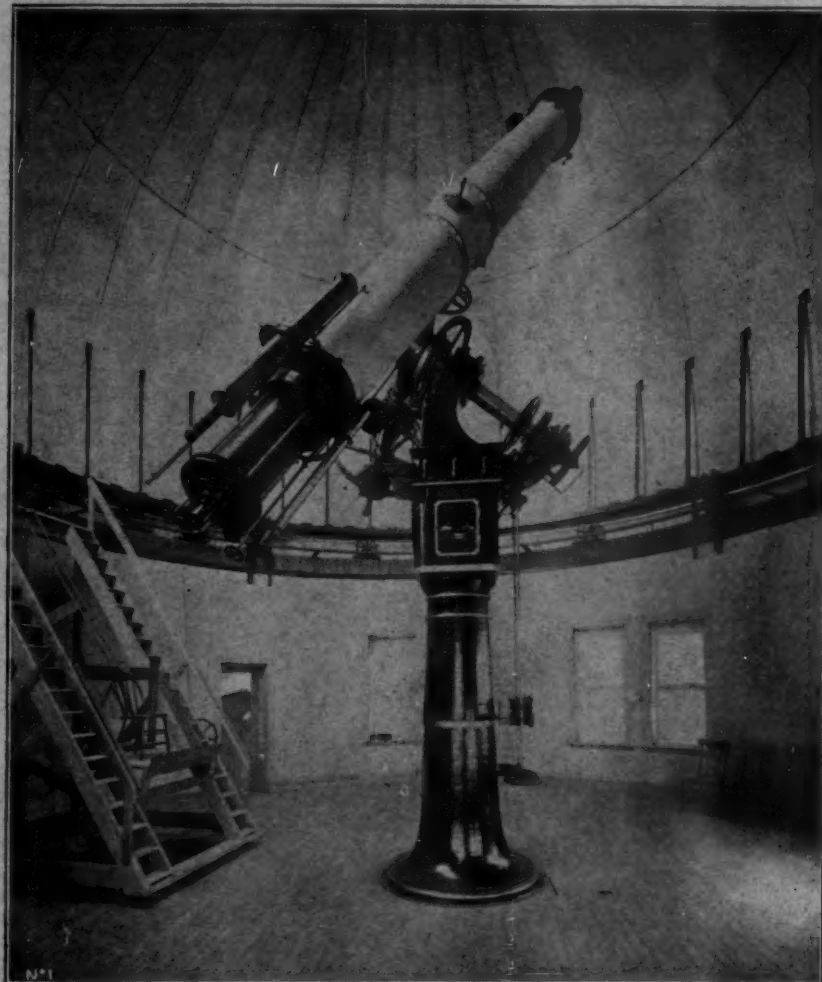

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Prerequisite: A thorough knowledge of Algebra, Plane Trigonometry, and Analytic Geometry, as given in the usual college text-books.

MR. DICKSON.

Plane Trigonometry.
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